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The Microscopic Characters of

Artificial Inorganic Solid Substances or Artificial Minerals

By A. N. WINCHELL

THE MICROSCOPIC CHARACTERS OF ARTIFICIAL INORGANIC SOLID SUBSTANCES OR ARTIFICIAL MINERALS

With a chapter on the Universal Stage by Richard Conrad Emmons. Second Edition. Cloth; 6 by 9; 403 pages; 311 figures; determinative tables.

By N. H. WINCHELL and A. N. WINCHELL

ELEMENTS OF OPTICAL MINERALOGY

AN INTRODUCTION TO MICROSCOPIC PETROGRAPHY

Part I. Principles and Methods. Fourth Edition. Cloth; 6 by 9; 248 pages; 270 figures.

Part II. Descriptions of Minerals. With Special Reference to their Optic and Microscopic Characters. Cloth; 6 by 9; 424 pages; 333 figures.

Part III. Determinative Tables. Second Edition. Cloth; 6 by 9; 204 pages; three folding charts.

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The Microscopic Characters of Artificial Inorganic Solid Substances or Artificial Minerals

BY

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WITH A CHAPTER ON THE UNIVERSAL STAGE

BY

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SECOND EDITION

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PREFACE TO SECOND EDITION

THE first edition of this work was published in 1927 as No. 4 of the University of Wisconsin Studies in Science. It seems desirable to include in the second edition a section devoted to the optical principles and methods of study which are used in the microscopic study of crystals so that the book may meet more fully the needs of students and others engaged in such work. With the same end in view a special chapter on the universal stage has been added from the pen of Professor R. C. Emmons. The text has been made more useful by the addition of about 300 illustrations and five plates.

Part I on "Principles and Methods," which did not appear in the first edition of this work, consists in large part of revised selections from the author's "Elements of Optical Mineralogy," Part I, 3d Edition, to which the reader may refer for directions for the study of crystals in convergent polarized light; Part II, "Descriptions of Artificial Inorganic Solid Substances," has been thoroughly revised with many changes and additions; and Part III, "Determinative Tables," has been entirely rewritten.

Each index of refraction of any artificial inorganic solid substance of definite composition and definite space lattice varies so little in different samples under given temperature and pressure conditions that the value may be considered absolutely constant to the fourth or fifth decimal place; on the contrary, each index of refraction of almost any natural mineral is not constant even to the third decimal place, because of variations in composition. Therefore, the general rule in this book is to give the values of indices of refraction of pure substances to the fourth decimal place and in three kinds of light (C, D and F), whereas values of indices of refraction of natural minerals are rarely significant beyond the third decimal place. The indices of refraction of some pure substances have not been measured with accuracy and accurate measures have not always been made on strictly pure material; in such cases the indices of refraction are given only to the second or third decimal place.

It is a pleasure to acknowledge the invaluable assistance which the author has received from various associates. He is especially indebted to Professor R. C. Emmons for the important chapter on the universal stage as well as for many suggestions regarding the descriptions of apparatus and other portions of the text. He has obtained unpublished data regarding the optical properties of certain substances through the kindness of Drs. H. E. Merwin, G. W. Morey, E. Posnjak, F. R. Bichowsky, E. T. Allen, N. L. Bowen, C. J. Ksanda and E. G. Zies of the Geophysical Laboratory, Professor C. W. Mason of Cornell University, Dr. V. A. Vigfusson of the University of Saskatchewan and others.

The title of the book has been modified to prevent misapprehension regarding its scope.

ALEXANDER N. WINCHELL.

MADISON, WISCONSIN

FROM THE PREFACE TO THE FIRST EDITION

WHILE preparing the second edition of Part II of the writer's "Optical Mineralogy," it seemed undesirable to attempt to discriminate between natural and artificial minerals since the distinctions between them are so vague and unstable. Therefore the manuscript was prepared so as to include all minerals, both natural and artificial, if their optic properties were sufficiently well known to permit their identification microscopically. More concretely stated, all inorganic substances were included whose indices of refraction had been measured. When the manuscript was completed it was found to be too long for one volume and therefore the part dealing with artificial minerals was eliminated for separate treatment as given in this book. The following account may accordingly be considered as a supplement to Part II[1] of the author's "Optical Mineralogy."

Undoubtedly some artificial substances, whose optic constants are known, have been omitted from this compilation, but the writer has spent many months searching all available literature for data (unfortunately almost never indexed), and trusts that he has achieved a reasonable measure of success.

Many minerals, like borax, are found in nature and are also produced artificially. In this work only those substances are included whose optic properties have been measured on artificial material.

* * * * * * * *

The description of each artificial substance is given usually in the following order:

Chemical name and composition, usually expressed merely by a formula.

Crystal system (and axial elements).

Physical characters, including crystal habit, twinning, cleavage, hardness (H), specific gravity (G), fusibility (F), and solubility.

Optic properties, including optic orientation, extinction angles, refringence, birefringence, optic sign, optic angle, dispersion, color, pleochroism and absorption.

---

[1] Published by John Wiley & Sons, Inc., New York, 1927.

Inversions in some cases described immediately after the composition.

Synthesis, described very briefly, if at all, and often referring rather to the method of producing crystals than to the formation of the compound.

It is obvious that a work of this kind is largely a compilation of all available data, and in its preparation the writer has made free use of the standard publications on the subject, including especially:

P. Groth: Chemische Krystallographie, vol. I–II, 1906, 1908.
Zeitschrift für Krystallographie, vol. I–LX, 1877–1924.
H. Dufet: Recueil de Données Numériques, vol. II, and vol. III, 1900.
H. R. Landolt and R. Bornstein: Physikalisch-chemische Tabellen, 5 Aufl., 1923.
L. J. Spencer: Tables Annuelles Internationelles de Constantes, etc., vol. I–V, for 1910–1922, published in 1912–1926.
E. S. Larsen: Microscopic Determination of the Nonopaque Minerals, 1921.

No attempt is made in this work to give the source of all the data which are included; so far as they are derived from the standard reference works already cited it is considered unnecessary to cite these repeatedly. On the other hand the author has aimed to give references to the source of all data from unusual sources or from current literature.

ALEXANDER N. WINCHELL.

MADISON, WIS.,
Oct. 1927

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EXPLANATION OF PLATES

(In pocket inside of back cover)

Plate I.—Relation between true and observed angles on the universal stage when the crystal and hemisphere differ in refringence ($\sin i = n \sin r$). (After Fedoroff.) This is used to correct angular readings between the normal to the inner stage (or the section) and the direction of observation. The correction is based, first, on the index of the crystal, and, second, on the index of the glass hemisphere that is being used. All angles to be used on Plate II must first be corrected on this graph or its equivalent. The procedure is shown in the key,—the observed angle as read on the scales is traced from the circumference to that circle which indicates the index of the crystal, thence along a vertical line (up or down) to that circle which indicates the index of the glass hemisphere, and thence radially to the circumference on which the true angle within the crystal is read.

Plate II.—Variation in the refractive index with change in angular position in a symmetry plane of the triaxial ellipsoid. ($\epsilon_1 = \epsilon\omega/\sqrt{\omega^2 \sin^2 \phi + \epsilon^2 \cos^2 \phi}$.) (The small triangle is intended only for substances of strong birefringence, and only for such substances is it necessary to make the indicated corrections for the position of the substance on the refractive scale).

The use of the diagram may be outlined as follows:

Assume that a crystal has been oriented with X, Y, or Z parallel to the axis of the microscope (which can always be done) and that two indices have been determined in this position by the double variation method. Assume, further, that it is impossible to rotate on a horizontal axis through 90° to either of the other two principal positions, which is a common difficulty. Then rotate, with the grain at extinction as far as is conveniently possible on that horizontal axis which permits the greater rotation (up to 90°), and rotate the lower nicol (or the stage), if necessary, to make its plane of vibration perpendicular to the axis of rotation. Note the amount of rotation of the horizontal axis and correct it according to Plate I. Measure the refractive index in the new position and find the difference in index between this value and that of the principal index already measured for the ray which vibrates in the same plane. This difference is found on the ordinate or abscissa as follows: If the rotation has caused a change from a greater to a smaller index, use the ordinate scale; if the rotation has caused a change from a smaller to a greater index, use the abscissa scale. Follow this value horizontally (or vertically) to the intersection with the proper degree of rotation line. Then follow the inclined line to its extremity where is indicated the total difference in index for a full 90° rotation. By simple addition or subtraction the third principal index may then be obtained.

For substances of stronger birefringence the smaller triangle is used similarly with this difference—if the index is not that for which the diagram was constructed, then a small correction must be applied. First determine the total difference in index as outlined for a 90° rotation. Select the proper small plat, follow the proper total "index-difference" curve to its intersection with the "degree of rotation" line (vertical) at which the reading was made. The correction is at the left.

Plate III.—Universal stage protractor. The diagram is a substitute for the Nikitin hemisphere. It gives the angular distance of the perpendicular to the inner stage from the axis of the microscope. This angle is corrected for refractive index on Plate I. After making the corrections and locating the modified positions on this plate, then such angles as V or $2V$, and angles to be used on Plate II, may be read. This plate is a stereographic projection of angular rotations in divisions of 10 degrees.

Plate IV.—Relation between optic angle and differences in principal refractive indices in a biaxial crystal. ($\sin^2 V = N_m - N_p/N_g - N_p$.) (After F. E. Wright.) If the three principal refractive indices of a crystal are known, the optic angle can be obtained quickly by means of this graph. The total birefringence ($N_g - N_p$) is found on the abscissa, and the partial birefringence ($N_g - N_m$ or $N_m - N_p$) is found on the ordinate. The inclined lines indicate V.

Plate V. -Artificial inorganic solid substances classified on the basis of birefringence optic sign, and refringence. The horizontal coordinate is refringence (N, N_o, or N_m) with a change of scale at 1.55, 1.75, and 2.00, and a range from 1.44 to 3.00. The vertical coordinate is birefringence ($N_g - N_p$) with zero birefringence (isotropic substances) in the middle of the diagram, the birefringence of positive substances from zero to 0.200 in the upper half, and that of negative substances from zero to 0.200 in the lower half of the diagram, with a change of scale at 0.020, 0.060, and 0.100. A few substances with optic properties outside these limits are located approximately by arrows or statement of optic data.

All the indices of refraction of any substance may be obtained readily from the diagram. If the substance is isotropic its position along the middle horizontal line gives its only index, N. The formula of each anisotropic substance is followed by a number which gives the value of its true optic angle ($2V$) in degrees. If the substance is uniaxial, its optic angle is 0°; its position on the diagram gives the value of N_o, the birefringence, and the optic sign. The value of N_e may be obtained by adding, for positive substances, or subtracting, for negative substances, the birefringence from N_o. If the substance is biaxial its position on the diagram gives its optic sign, its refringence, N_m, and its birefringence, $N_g - N_p$. By using the value of the optic angle of the substance the small diagram in the lower right-hand corner gives the fraction of the birefringence which must be added to N_m to obtain N_g and also the fraction which must be subtracted to obtain N_p.

ABBREVIATIONS AND SYMBOLS

(Chemical symbols and names of periodicals not included)

A, B = Optic axes of biaxial crystals.
A, B, C, D, E, F, G, H (after indices of refraction) = various types of monochromatic light.
a = front and rear crystal axis.
α = angle between crystal axes *b* and *c*.
b = right and left crystal axis.
β = angle between crystal axes *a* and *c*.
Biref. = birefringent.
°C. = degree Centigrade.
c = vertical crystal axis.
γ = angle between crystal axes *a* and *b*.
Cleav. = cleavage.
Comp. = composition.
D (after index of refraction) = monochromatic light of the D doublet.
E = extraordinary ray.
2E = the apparent optic axial angle measured in air.
ϵ = index of refraction for the extraordinary ray.
Ext. = extinction.
F. = fusibility.
G. = specific gravity.
H. = hardness.
H (in the tables) = hexagonal.
2H = the apparent optic axial angle measured in oil.
Hex. = hexagonal.
Isom. = isometric.
Lg. = large.
Li (after index of refraction) = lithium (red) light.
λ = wave length of monochromatic light.
M (in the tables) = monoclinic.
m = an indefinite number.
μ = a thousandth of a millimeter, or a micron.
mμ = a millionth of a millimeter.
Max. = maximum.
Mod. = moderate.
Mono. = monoclinic.
N = index of refraction.
Na (after index of refraction) = sodium (yellow) light.
N_e = index of refraction for the extraordinary ray.
N_g = greatest index of refraction = γ of German writers.

N_m = intermediate ("mean") index of refraction = β of German writers.
N_o = index of refraction for the ordinary ray.
N_p = least ("petty") index of refraction = α of German writers.
n = an indefinite number.
O = ordinary ray.
O (in the tables) = orthorhombic.
Opt. Ax. = optic axis.
Orth. = orthorhombic.
Q = tetragonal (quadratic) crystal system.
R = rhombohedral.
ρ = red (light).
$\rho > v$ or $\rho < v$ (after optic angle) signifies that the optic axial angle in red light is greater than or less than the optic angle in violet light.
Sm. = small.
Sol. = solvent.
Syst. = system.
T (in the tables) = triclinic.
Tetr. = tetragonal.
Tl (after index of refraction) = thallium (green) light.
Tric. = triclinic.
Trig. = trigonal or rhombohedral.
2V = the true angle between the optic axes.
v = violet (light).
X = the vibration direction of the fastest ray = $\mathfrak{a}$ of German writers.
X > Y, X < Z, etc. = absorption greater (or less) in the direction of X than in the direction of Y (or Z), etc.
Y = the vibration direction of the intermediate ray = $\mathfrak{b}$ of German writers.
Z = the vibration direction of slowest ray = $\mathfrak{c}$ of German writers.
$\wedge$ = angle; for example, $Z \wedge \mathfrak{c}$ = the angle between Z and c.
$>$ = greater than.
$<$ = less than.
100, 010, 001, 110, etc. = Miller symbols of crystal faces and forms.
$\perp$ = normal to.
$\parallel$ = parallel; this is often omitted, as in the statement: "the optic plane is 010"; or it is replaced by "=," as in "X = a."

The optic sign of a substance is expressed by (+) or (−) before the expression for the optic angle; for example, $(+)2V = 50°$ signifies that the true optic angle is 50° measured about Z and the optic sign is positive.

In monoclinic crystals the extinction angle is commonly measured from the vertical axis c to X, Y, or Z; this angle is positive if it lies in the obtuse angle β and negative if it is in the acute angle β between a and c.

The sign of elongation of crystals is positive if Z (the vibration direction of the slow ray) is parallel with, or less than 45° from, the direction of elongation; it is negative if X occupies this position; it is plus or minus (±) if Y occupies the position named.

PART I

PRINCIPLES AND METHODS

INTRODUCTION

DRAWINGS, PROJECTIONS AND DIAGRAMS

Drawings of crystals are representations of solid objects in one plane—the plane of the paper—and therefore require a projection.

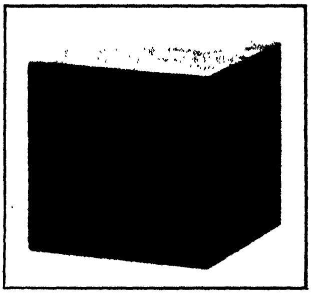

FIG. 1.—Cube, photographed in clinographic projection.

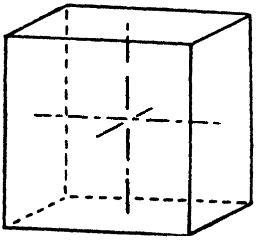

FIG. 2.—Cube, drawn in clinographic projection.

The projection used in nearly all cases is not a true perspective, but assumes that the observer is at infinitive distance, so that all lines, which are parallel on the crystal, are also parallel in the drawing. Furthermore, the observer is not supposed to be directly in front of the crystal, but above and to the right so that the top and right-hand side are in view as well as the front. Ordinary crystal drawings, made in this way, are in *clinographic projection,* the rotation of the crystal from the position directly in front of the observer being 18° 26′ to the left on the vertical axis and 9° 28′ downward on the right and left axis. The relation between a photograph of a crystal in its proper position for such a drawing and the drawing itself is illustrated by Figs. 1 and 2.

In all ordinary cases crystal drawings differ from photographs in one important respect, namely, they assume that the crystal has developed so as to have full geometrical symmetry, that is, corresponding faces are assumed to be at equal distances from the center as well as to be in their true angular position with respect to other faces and the crystal axes.

Certain other types of projection do not give a picture of the crystal, but are very useful since they present a graphic expression of the symmetry and of all the angular relations of the crystal much more clearly and exactly than any picture.

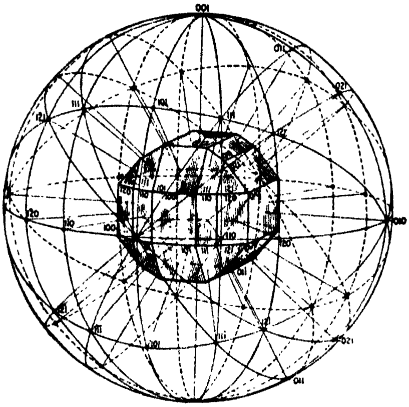

Fig. 3.—Derivation of spherical projection.

In *spherical projection* the crystal is supposed to have its center at the center of an enclosing sphere, as in Fig. 3. From the common center a line is drawn normal to each crystal face and this line is continued until it intersects the enclosing sphere. The point of intersection is known as the pole of the given face. The poles of all faces in one zone (that is parallel to one line in the crystal) are in one great circle in the sphere. Conversely, all faces whose poles are in one great circle belong to one zone in the crystal. A face whose pole falls at the intersection of two or more great circles belongs to two or more independent zones in the crystal. The angular relations between the faces are retained exactly on the sphere; the angles on the sphere, being the angles between normals to the faces, are the supplements of the actual interior angles between the faces of the crystals. These angles between the normals to the faces are the "normal interfacial angles" commonly recorded in all the literature on the subject.

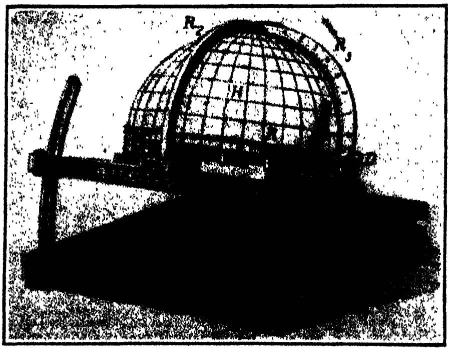

Fig. 4.—Hemisphere of Nikitin.

It is customary to place the crystal so that the vertical axis is normal to the equatorial plane of the sphere; then an orthorhombic crystal has the pole of the face 001 at the north pole of the sphere and any crystal has the faces of the prism zone (100, 110, 010, 110, etc.) on the equatorial circle. Since crystals are commonly alike at the two ends of the vertical axis, it is unnecessary to use more than half the sphere; the upper or northern hemisphere is commonly employed.

The chief disadvantage of spherical projection is that the surface of projection is curved and therefore can be shown in a plane figure only pictorially or by means of another projection. To use the spherical projection directly an actual spherical surface is needed; a hemisphere, such as that of Nikitin[1] (Fig. 4), with movable graduated circles, serves the purpose well. The most important method used to convert a spherical projection into a plane figure is by means of the stereographic projection.

The *stereographic projection* may be derived from the spherical projection by projecting each pole on the upper hemisphere onto the equatorial plane of the sphere by means of a straight line from the pole of the face to the south pole of the sphere, as shown in Fig. 5. In the figure it is evident that lines (of projection) are drawn from each pole on the upper hemisphere to the south pole of the sphere; the points where these lines intersect the equatorial plane (which is the plane of projection) are the poles of the respective faces in a stereographic projection. The stereographic projection of the crystal of Fig. 3, derived from the spherical projection as shown in Fig. 5, is represented in full view in Fig. 6. It is important to note that all great circles of the spherical projection appear as arcs of true circles in the stereographic projection, the only apparent exception being that all great

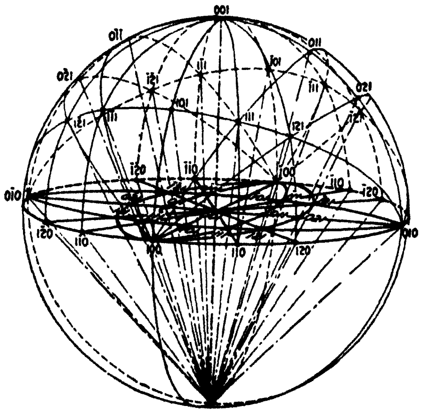

FIG. 5.—Derivation of stereographic projection.

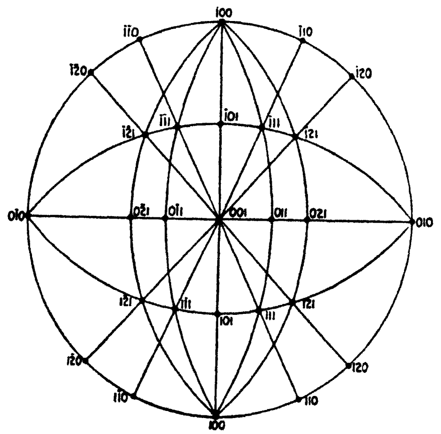

FIG. 6.—Example of stereographic projection.

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[1] *Zeit. Kryst.*, XLVIII, 1910, p. 379.

circles passing through both the north and south poles of the spherical projection appear as straight lines in the stereographic projection (but such lines are arcs of circles of infinite radius). The poles of all faces which are parallel to the vertical axis of the crystal are on the equator of the spherical projection and remain at the same points on the boundary circle (equator) of the stereographic projection. The pole of a face normal to the vertical axis of the crystal is at the north pole of the spherical projection and at the center of the stereographic projection. Penfield[2] devised convenient protractors for plotting and for measuring angles in stereographic projections of definite radius.

The stereographic projection is well adapted to show all the optic properties of a single crystal, as illustrated in its use to show the properties of albite, etc., by Michel Lévy. It can be used to show variations in the position of optic elements in an isomorphous series, but is not well adapted to show variations in refringence, birefringence, optic angle, or extinction angles in such a series.

Diagrams for binary series.—The ordinary system of two coordinates is commonly used to show variations in properties in an isomorphous binary series, that is, in a case involving only two molecules, such as plagioclase. One coordinate—commonly the horizontal—is taken to represent variation in composition from one pure molecule at one end of the line to the other pure molecule at the other end of the line. By dividing this line into ten equal parts, each division point represents simple decimal proportions of the two molecules. Then the other coordinate can be used to represent any property of the substance, such as the mean index of refraction, the specific gravity, the extinction angle, or the optic angle. By placing one or more suitable scales on this coordinate the numerical value of the index or other property can be read directly from the diagram for any composition shown, and the variations of the properties with variations in composition through the series can be seen conveniently. Fig. 7 furnishes an illustration of such a diagram.

In some cases there are two kinds of variations in composition in an isomorphous system which are quite independent. One of the simplest cases of this kind is found in the spinel group in which $MgAl_2O_4$ may vary in one way to $FeAl_2O_4$, and, wholly independent of this variation, there may be another variation from $MgAl_2O_4$ to $MgCr_2O_4$. In such cases each variation in composition should be plotted as one of the usual coordinates, as in Fig. 8, in which $MgAl_2O_4$ may be assumed to be at A; then $FeAl_2O_4$ may be at B, and $MgCr_2O_4$ at C. It is evident that if both these variations are assumed to occur the

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[2] *Am. Jour. Sci.*, CLXI, 1901, p. 10.

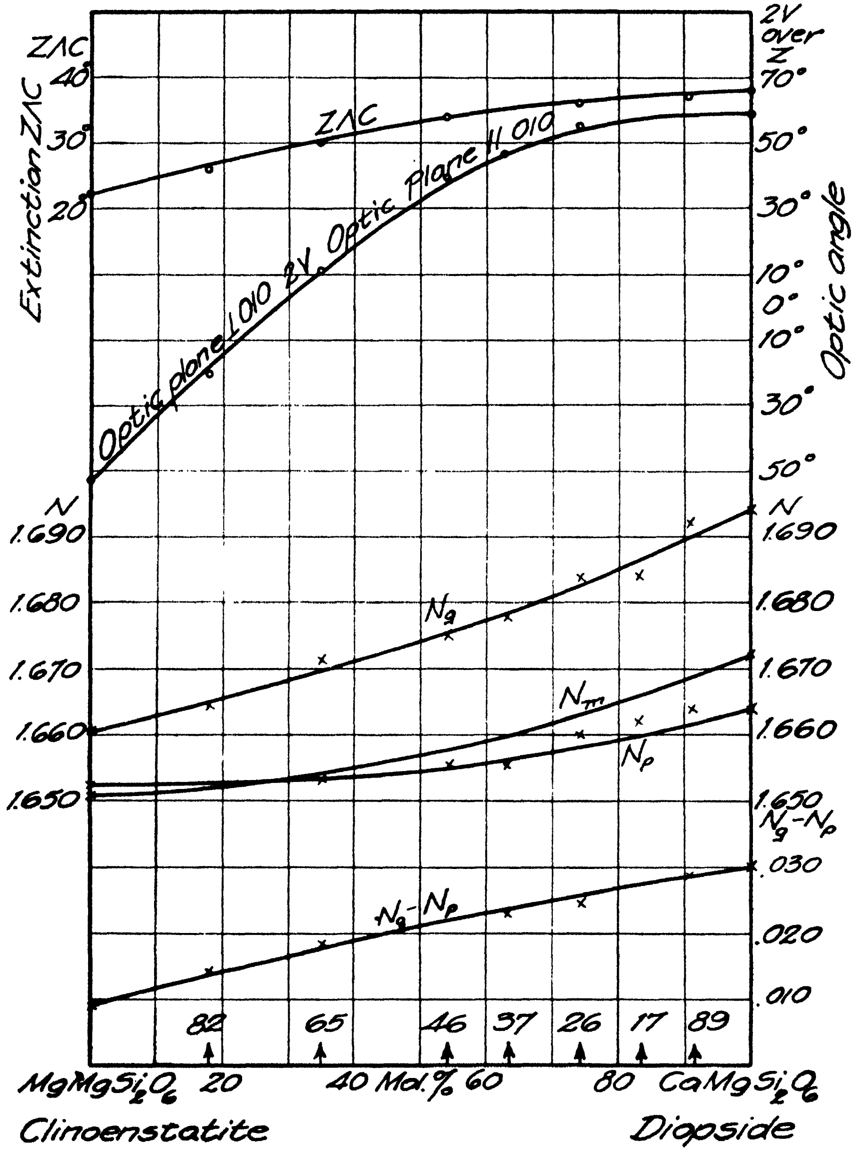

FIG. 7.—Variations in optic properties with variation in composition in a binary series.

result will be $FeCr_2O_4$, and this molecule should be used to complete the square, as at D. Now, if the opposite sides of the square are divided in tenths and corresponding divisions are connected by straight lines, the whole area of the square may be divided so that the percentage composition may be easily read at any point. For example, the point P_1 represents 90 per cent of the iron molecules (B and D) and 10 per cent of the magnesium molecules (A and C); it also represents 80 per cent of the aluminum molecules (A and B) and 20 per cent of the chromium molecules (C and D); therefore it represents 90 per cent of 80 per cent or 72 per cent of B, 10 per cent of 80 per cent or 8 per cent of A, 90 per cent of 20 per cent or 18 per cent of D, and 10 per cent of 20 per cent or 2 per cent of C. Similarly, P_2 represents 42 per cent of A, 18 per cent of B, 28 per cent of C, and 12 per cent of D. Variations in physical properties are not shown as easily on such a diagram as on one for a binary system, but they can be shown,

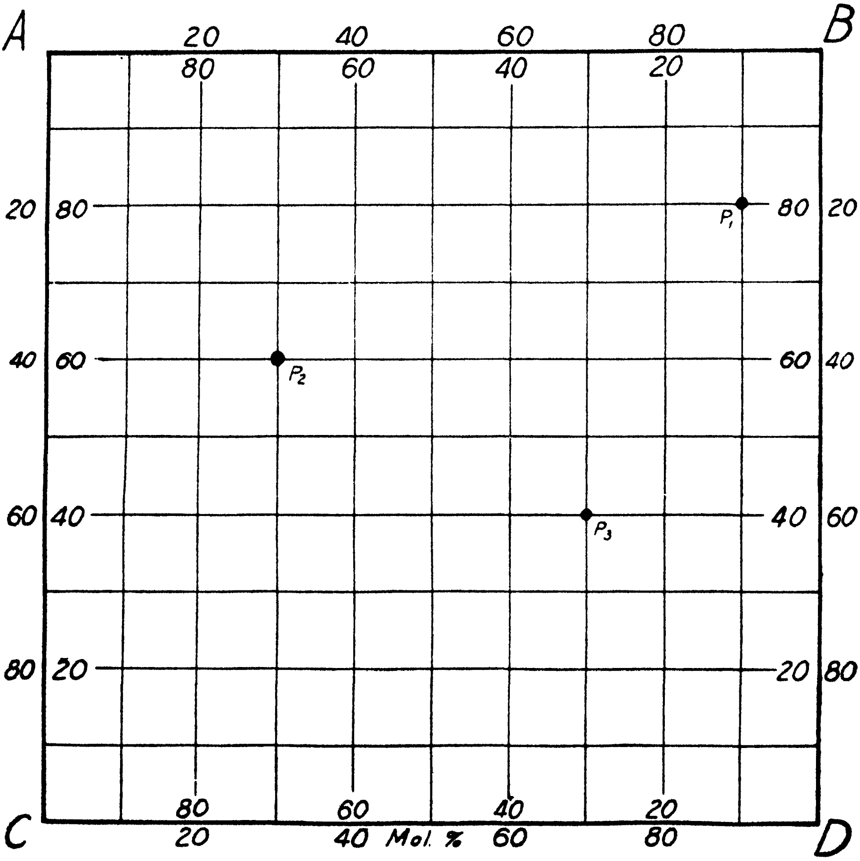

FIG. 8.—Diagram for two independent variables leading to four molecules.

either as lines of equal properties, like contours, or as measured above the plane of the square in a solid model. It is necessary to use the method of "contours" in plane figures. An illustration may be found in Fig. 9.

Diagrams for ternary systems.—In some cases a mineral molecule varies in composition only as to one component, but more than one other element may take the place of this component. A simple illustration of such a case is furnished by $MgCO_3$, which may vary to $FeCO_3$ or to $MnCO_3$ or to mix-crystals containing all three of these molecules. In this instance there must always be exactly 100 (Mg + Fe + Mn) atoms for each 100 CO_3 groups. That is, the sum of Mg + Fe + Mn is a constant in all parts of the system, and this constant may be taken as 100, for convenience. Such a system may be represented on a triangle, the three corners of which represent the three pure molecules, as in any one of the triangles of Fig. 10. Then by dividing the sides of the triangle into tenths and connecting these points by straight lines, as in the figure, the whole triangle is divided so that the composition represented at any point may be read off very easily. For example, the point P_1 represents 40 per cent of A, 10 per cent of B, and 50 per cent of C; the point P_3 represents 50 per cent of B, 30 per cent of D, and

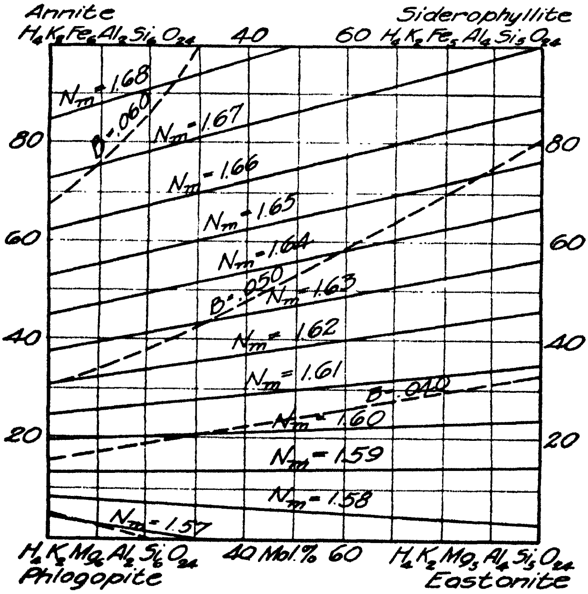

FIG. 9.—Variations in optic properties with variations in composition in a system of four molecules.

20 per cent of E. Of course, the physical properties can be shown on such a triangle just as on a square, either by distances measured above the plane of the triangle in a solid model, or by contours. They are shown by " contours " in Fig. 11 for the tephroite-forsterite-fayalite system. The properties of two of the three binary series of this system are only approximately known, and data in the ternary field

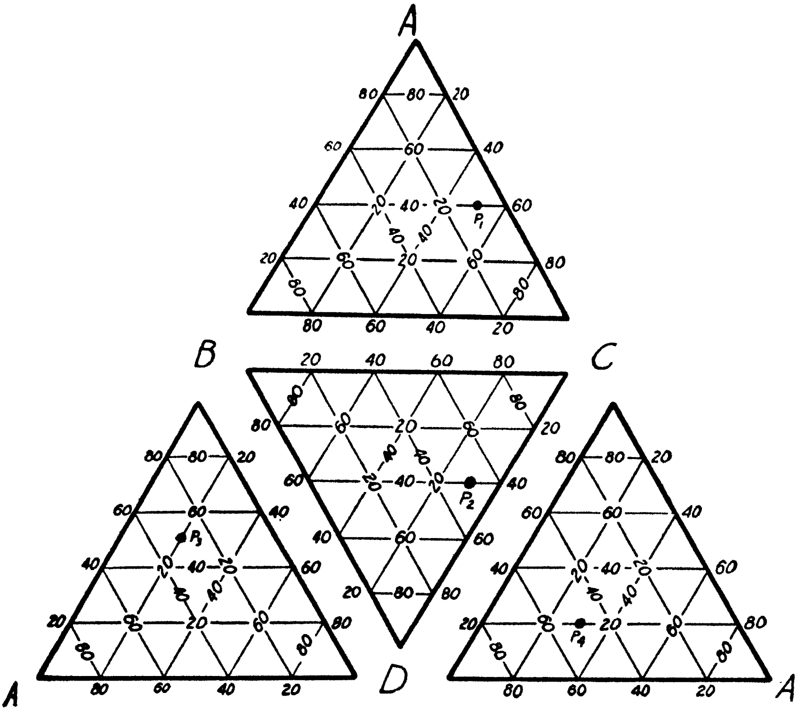

FIG. 10.—Diagram for three (and four) independent variables.

are very scanty, so the " contours " are all drawn as straight lines; in general, such lines are straight or only moderately curved.

Diagrams for quaternary systems.—In some cases variations in one component of a molecule may lead to three other molecules. For example, chalcanthite ($CuSO_4 \cdot 5H_2O$) may vary to siderotil ($FeSO_4 \cdot 5H_2O$) or to cobalt-chalcanthite ($CoSO_4 \cdot 5H_2O$) or to manganese-chalcanthite[3] ($MnSO_4 \cdot 5H_2O$). In this case the constant which may be considered 100 is Cu + Fe + Co + Mn. A tetrahedron is required to illustrate all possible mixtures of the four molecules, but, fortunately, in minerals, one of the four components is nearly always so inferior in amount that the point representing the composition is very near, and may be considered to be on, one side of the tetrahedron. The four sides of the tetrahedron may be drawn,

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[3] Continuity in all parts of this system has not been demonstrated.

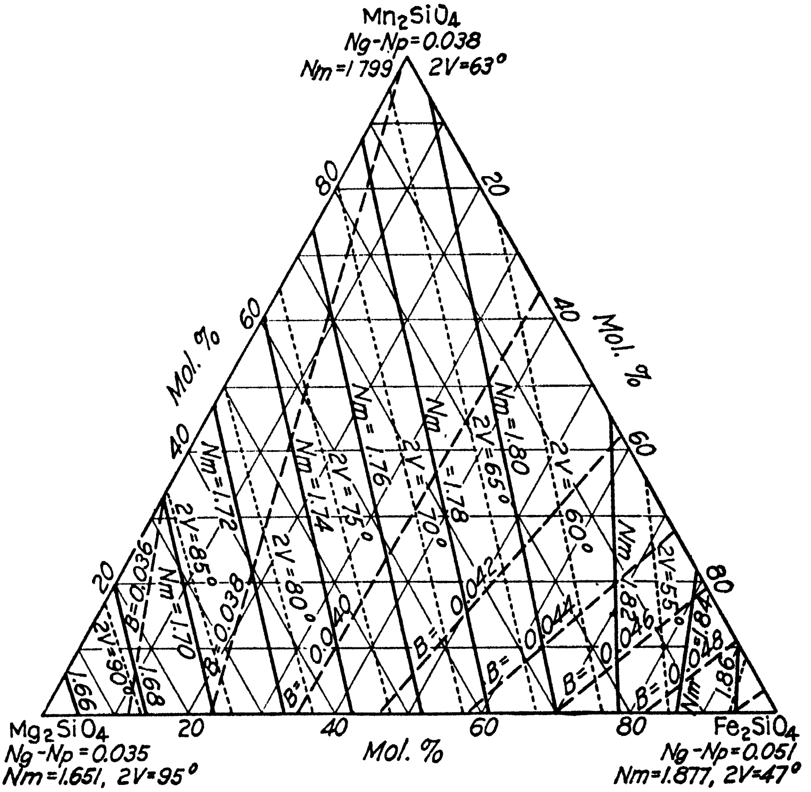

FIG. 11.—Variations in optic properties with variations in composition in a system of three independent variables.

therefore, as in Fig. 10, and practically all the actual cases can be represented on one of the four triangles. The triangle BCD may be considered the base of the tetrahedron, and the other triangles the three sides having the common apex, A.

CHAPTER I

CRYSTALS

Introduction: The intelligent study of the optic and microscopic characters of artificial inorganic solid substances (artificial minerals[1]) requires at least an elementary knowledge of the properties of solids, that is, of crystals, and also an understanding of some of the simplest principles of optics. Therefore, before describing the substances themselves, it is desirable to review briefly the properties of crystals and also some of the principles of optics.

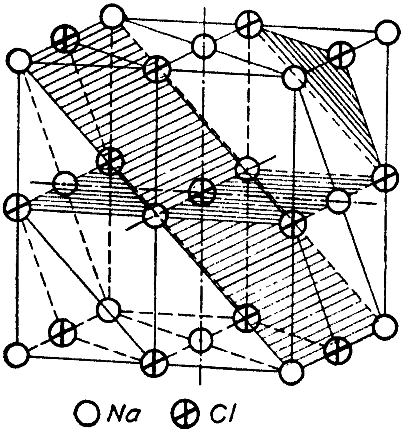

Fig. 12.—Space lattice of halite crystals.

Crystals are bodies bounded by smooth surfaces having their constituent atoms[2] arranged in a definite and regular order. Crystals are produced when a substance passes from the state of a fluid to that of a solid, under conditions favorable to the natural adjustment of the atoms, so that they form networks or "space lattices," such that there is the same arrangement of atoms of one kind about any one atom as about any other one of the same kind within the crystal. In case this natural adjustment is attained, the interatomic forces are in equilibrium. In general, liquids and gases are composed of molecules, which are groups of atoms; while most crystals (at least those of inorganic substances) are now known to be built of atoms, in some cases in such arrangement as to suggest the presence of radicals, or parts of molecules, like CO_3, but free from molecules, unless a whole crystal may be considered an enormous molecule.

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[1] Some writers regard minerals as necessarily products of nature, but this limitation is so arbitrary and difficult of application in some cases that the author considers it better to regard all artificial inorganic solid substances as "artificial minerals," thus securing a name which is easily understood and has the merit of brevity.

[2] An atom is the smallest portion of an element which can enter into chemical combination; each element has atoms of definite constant weight.

One of the simplest types of space lattices is illustrated in Fig. 12; this is the arrangement in ordinary salt (sodium chloride or halite). Three kinds of planes passing through such crystals are shown by the shading. Another type of space lattice, showing a group like a radical, is shown in Fig. 13; this is the arrangement of the atoms in calcite, magnesite, siderite, and rhodochrosite.

If a solid substance has the regular internal arrangement of atoms without smooth external faces, it is said to be crystalline or to have crystal structure. A compact aggregate of crystalline material is described as massive. A single unit, having the same crystal structure throughout, but devoid of crystal faces, is known as an *anhedron.* If a substance has neither the smooth external faces nor the regular internal arrangement of atoms, it is said to be amorphous. This is the condition of a piece of glass, of opal, etc. Some substances solidify to the amorphous state if they are cooled very rapidly, because time is necessary to permit the atoms to change from the molecular groupings into regular arrangements, or lattices, in which the interatomic forces are in equilibrium.

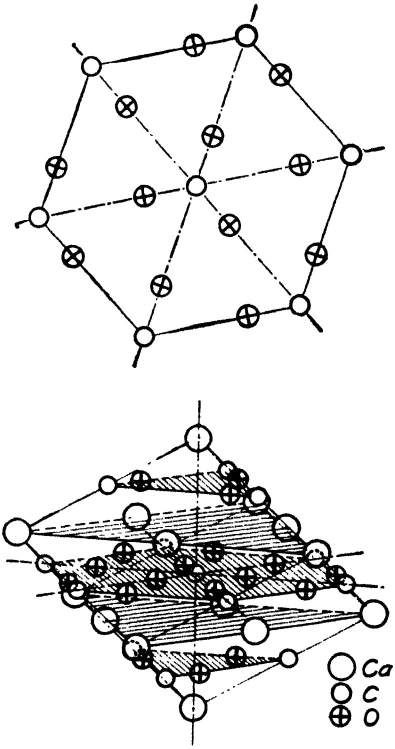

FIG. 13.—Space lattice of calcite crystals.

Symmetry of crystals.—All the faces of a crystal, as well as all the constituent atoms, are arranged in accordance with certain elements of symmetry, which are fixed in their position for a given crystal, and determine, not merely its external form, but also the distribution of all the internal physical characters. The essential feature of symmetry is repetition. Thus, a right triangle ABC (Fig. 14) may be divided symmetrically by a line DE, if every line, point and angle on one side of DE is repeated on the other side in the same relative position. There are three types of symmetry commonly recognized in crystals, namely, symmetry with respect to (1) a point, (2) a line, (3) a plane. One, two, or three of these types of symmetry may be present in a given crystal.

A crystal is symmetrical with respect to a point when for each face and edge on one side of the point (or center) there is a similar face and edge directly on the other side of the center. This is the only element of symmetry in triclinic crystals, as illustrated in Figs. 49 and 50.

A crystal is symmetrical with respect to a line (or axis) when a rotation of less than 360° about this line causes the crystal to occupy exactly the same position in space as at first. If a rotation of 180° produces the first repetition of position, there are two repetitions in a complete rotation, and the line is said to be an axis of twofold or binary symmetry, as illustrated by each axis in Figs. 39–43. An axis of threefold or ternary symmetry is illustrated by the vertical axis in Figs. 31–36; one of fourfold symmetry is shown by each axis in Figs. 16–20; and the vertical axis in Figs. 28–30 is an axis of sixfold symmetry.

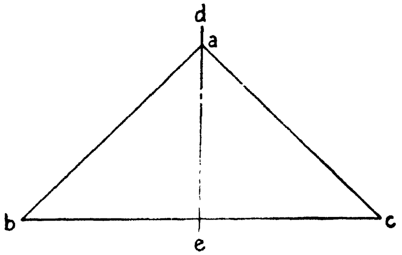

FIG. 14.—Symmetry of a simple plane figure.

A crystal is symmetrical with respect to a plane when for each face or edge on one side of the plane there is a similar face or edge directly opposite on the other side, so that one side is the mirror image (in the given plane) of the other. Each axial plane is a plane of symmetry in Figs. 16–21, 24–29 and 37–43.

All the corresponding interfacial angles on all crystals of the same species are constant; that is, they all have the same value. This is a consequence of the fact that the external faces of a crystal are determined by the internal structure, and of the further fact that all crystals of the same species have the same internal structure.

Crystal axes.—In the description of the form of a crystal, especially as regards the position of its faces, it is convenient to assume, as is done in analytical geometry, certain axes of reference, passing through the center of the ideal form. These imaginary lines are called crystallographic axes. Their directions are more or less fixed by the symmetry of the crystal, for an axis of symmetry is a crystallographic axis, in most cases. These axes (denoted *a*, *b*, and *c*, if unequal in length) are shown in their normal position in Fig. 15.

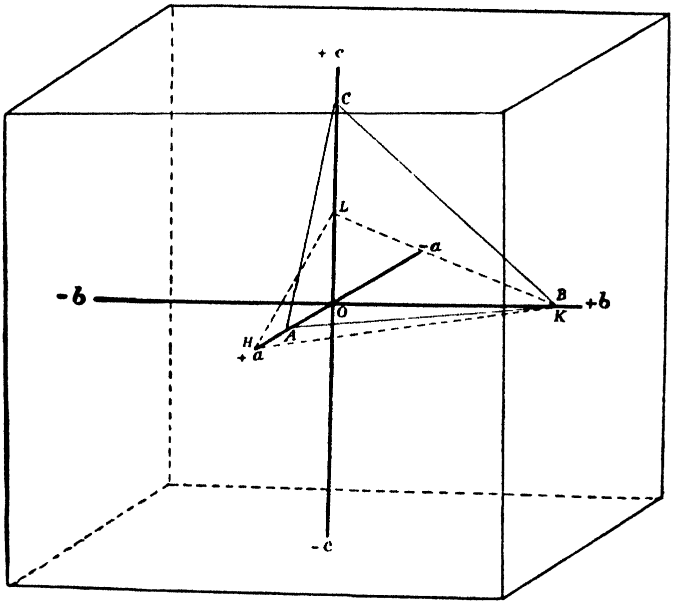

FIG. 15.—Crystal axes and intersecting planes.

Parameters and symbols.—The position of any face of a crystal is conveniently expressed by stating the lengths on the axes at which the face (or its extension) cuts these axes. These lengths are known as the coordinates of the plane. A simple mathematical ratio exists between the coordinates of all planes which are possible on all crystals of the same species. For example, in Fig. 15, the plane *ABC* cuts the axis *a* at a distance which may be 19 millimeters, the axis *b* at 36 millimeters, and the axis *c* at 32 millimeters. Then 19, 36, and 32 are the coordinates of *ABC*. Another face may have coordinates which are entirely different, for example, 28.5, 27 and 12 mm. The coordinates are always written in the same order, and it is therefore unnecessary to write the axes. The second set of coordinates divided by the first set gives fractions which express the position of the second plane with respect to the first, as follows: $\frac{285}{190}$, $\frac{27}{36}$, $\frac{12}{32}$. In order to simplify these ratios, either set of coordinates may be multiplied (or divided) by any suitable number (an operation which is equivalent to moving the plane parallel with itself, maintaining constantly the same *relative* position on the axes). For example, if the second set of coordinates be multiplied by $\frac{8}{3}$ so as to make the ratio unity on *c*, the fractions become $\frac{76}{19}$, $\frac{72}{36}$, $\frac{32}{32}$, which equal 4, 2, 1. Again, if the second set of coordinates be multiplied by $\frac{4}{3}$, the fractions become $\frac{38}{19}$, $\frac{36}{36}$, $\frac{16}{32}$, or 2, 1, $\frac{1}{2}$. This expresses the relative position of *HKL* (of Fig. 15) as compared with *ABC*. Numbers of this kind, which express in their simplest terms the relative positions of faces, are known as the parameters of the faces. The Miller symbols may be obtained from the parameters of any face by taking the reciprocal of each number and then clearing of fraction, if necessary. Accordingly, the Miller symbols of *HKL* are obtained by taking the reciprocals of the parameters 2, 1, ½, which are ½, 1 2, and clearing of fractions, with the following result: 1, 2, 4. The plane at the end of the *b* axis parallel with *a* and *c* has the parameters ∞, 1, ∞; since the reciprocal of ∞ is 0, the Miller symbols of the plane are 010. A plane in any octant is exactly expressed by using negative signs over the Miller symbols whenever the plane cuts an axis in the negative direction (see Fig. 15).

A **crystal form** includes all the faces of a crystal which are required by the symmetry if one face is present. Thus, referring to Fig. 15, if the face *HKL* or 124 is present on an orthorhombic crystal having three planes of symmetry at right angles, the crystal form would consist of eight faces having the following symbols: 124, $\bar{1}24$, $\overline{12}4$, $1\bar{2}4$, $12\bar{4}$, $\bar{1}2\bar{4}$, $\overline{124}$, $1\overline{24}$.

All crystals may be classified as belonging to six different crystal systems, distinguished by the relative lengths and angular inclinations of the assumed crystallographic axes. These systems are called the isometric, tetragonal, hexagonal, orthorhombic, monoclinic, and triclinic.

Isometric System.—All crystals which are referred to the isometric system have three equal rectangular axes. The forms of the system are numerous, but many of them are of no importance in the microscopic study of crystallized substances. Those of the highest grade of symmetry are the cube, octahedron, dodecahedron, trisoctahedron, trapezohedron, tetrahexahedron, and hexoctahedron; combinations of these forms, such as the octahedron and cube of Fig. 18, are very common. They have three principal[3] planes of symmetry parallel with the faces of the cube whose intersections determine the position of the crystallographic axes; they have also six auxiliary planes of symmetry, which bisect the angles between the principal planes, and are parallel with the faces of the dodecahedron. They have, further, three axes of fourfold symmetry coincident with the crystal axes, four axes of threefold symmetry normal to the octahedral faces, six axes of twofold symmetry normal to the dodecahedral faces, and a center of symmetry.

The **cube**, Fig. 16, is a form assumed by some crystals of fluorite.

The **octahedron,** Fig. 17, is a common form of spinel and alum; sections may be squares, rhombs, hexagons, or triangles.

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[3] A principal plane of symmetry is one containing two or more like axes of symmetry.

The dodecahedron, Fig. 19, is a form shown by garnet; sections are apt to be hexagons.

The trapezohedron, Fig. 20, is so common in leucite that the form is sometimes called the *leucitohedron;* the same form is common in crystals of $Ca_3Al_2O_6 \cdot 6H_2O$.

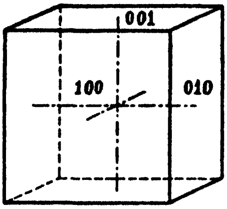

FIG. 16.—Cube.

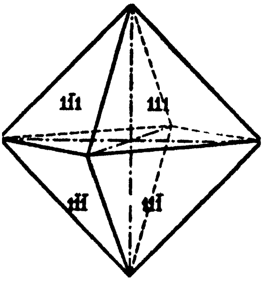

FIG. 17.—Octahedron.

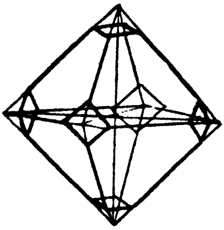

FIG. 18.—Combination of cube and octahedron.

The **pyritohedron,** Fig. 21, is so named because shown so often by pyrite.

The **tetrahedron,** Fig. 22, is a form often shown by sphalerite and diamond.

Each form of the isometric system completely encloses space and can occur alone; each one is therefore a geometrical solid, and has its

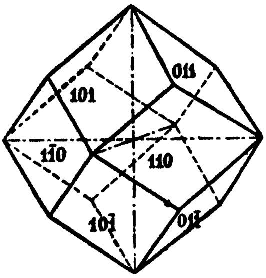

FIG. 19.—Rhombic dodecahedron.

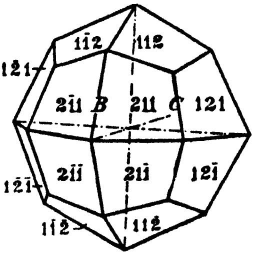

FIG. 20.—Trapezohedron.

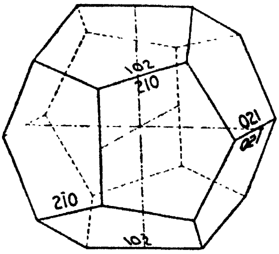

FIG. 21.—Pyritohedron.

special name, as illustrated above. In the other crystal systems, most of the crystal forms do not completely enclose space and cannot occur alone. Most of them belong to three types, namely:

1. **Pyramids,** which are forms each of whose faces cuts all three crystal axes.

2. **Prisms,** which are forms each of whose faces cuts the two lateral axes and is parallel to the vertical axis.

3. **Pinacoids,** which are forms each of whose faces cuts only one axis and is parallel to the other two.

Tetragonal System.—All crystals which are referred to the tetragonal system have three rectangular axes, two being of equal length, and the third, which is the vertical axis, of unequal length, as in Fig. 23. The forms of this system include the base, unit prism, diametral prism, ditetragonal prism, unit pyramid, diametral pyramid, and ditetragonal pyramid. These forms have one principal plane of symmetry parallel to the base, two axial planes of symmetry normal to the base (each including two crystal axes), and two other planes of symmetry bisecting the angles between the axial planes; they have also one axis of fourfold symmetry coincident with the vertical axis, and four axes of twofold symmetry parallel with the base, two being coincident with the lateral axes and the other two bisecting their angles; they have a center of symmetry.

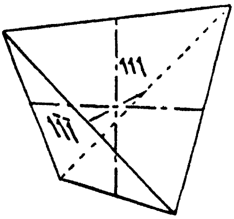

FIG. 22.—Tetrahedron.

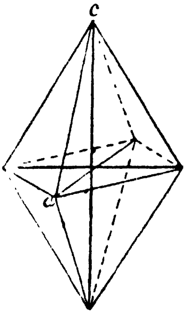

FIG. 23.—Axes within tetragonal pyramid.

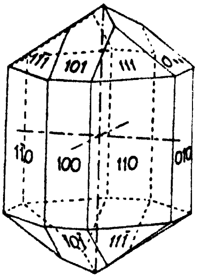

FIG. 24.—Unit and diametral tetragonal prisms and pyramids; cassiterite—SnO_2.

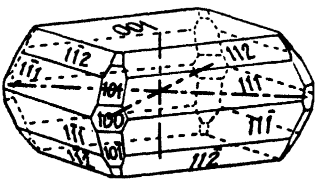

FIG. 25.—Unit and diametral pyramids and base; $NiSO_4\cdot6H_2O$.

The **base** or **basal pinacoid** consists of only two faces (001 and $00\bar{1}$); it is present on some crystals of $NiSO_4\cdot6H_2O$ (Fig. 25) and of meionite.

The **unit prism** consists of four faces (110, $1\bar{1}0$, $\bar{1}\bar{1}0$, and $\bar{1}10$); it is common on cassiterite (Fig. 24). Sections are apt to be squares.

The **diametral prism**[4] consists of four faces (100, 010, $\bar{1}00$, and $0\bar{1}0$);

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[4] The diametral prism is called a prism rather than a pinacoid because another selection of the position of the lateral axes—equally correct—would make it conform to the definition of a prism, and because it is geometrically a prism.

it is found on some crystals of H_2KPO_4 (Fig. 26); sections of this form alone are often squares.

The **ditetragonal prism** consists of eight faces (for example: 210, 120, $\bar{1}20$, $\bar{2}10$, $\bar{2}\bar{1}0$, $\bar{1}\bar{2}0$, $1\bar{2}0$, and $2\bar{1}0$).

The **ditetragonal pyramid** consists of sixteen faces; these are rare on artificial crystals.

The **unit pyramid** consists of eight faces, illustrated by some of the terminal faces in Fig. 24.

The **diametral pyramid**[5] consists of eight faces (101, 011, 110, $0\bar{1}1$, $10\bar{1}$, $01\bar{1}$, $\bar{1}0\bar{1}$, and $0\bar{1}\bar{1}$), which are present in combination with the unit pyramid as terminal faces in Fig. 26.

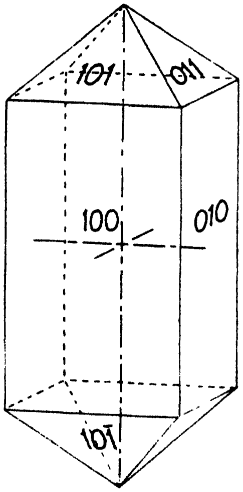

FIG. 26. Diametral tetragonal prism and pyramid; H_2KPO_4.

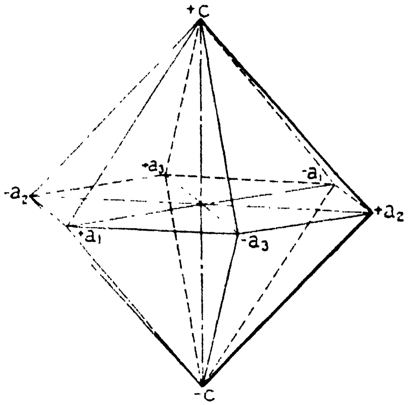

FIG. 27.—Axes within hexagonal pyramid.

Hexagonal System.—All crystals which belong to the hexagonal system have three equal axes making angles of 60° in one plane, and one unequal axis normal to this plane, as shown in Fig. 27. The hexagonal system consists of two parts which differ distinctly in symmetry and are known as the hexagonal and trigonal divisions.

Hexagonal Division.—All crystals of the hexagonal division have a vertical axis of sixfold symmetry; the forms of highest grade of symmetry have also a principal plane of symmetry parallel with the base, three axial planes of symmetry normal to the base (each including two crystal axes), and three other planes of symmetry bisecting the angles between the axial planes. They have also six axes of twofold symmetry (three being coincident with the lateral crystal axes and the other three bisecting their angles) as well as a center of symmetry. The forms of this division include the base, unit prism, diametral prism, dihexagonal prism, unit pyramid, diametral pyramid, and dihexagonal pyramid.

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[5] The diametral pyramid is called a pyramid, though it does not conform to the definition of a pyramid, because another selection of the position of the lateral axes—equally correct—would make it conform, and because geometrically it is a double pyramid.

The **base on basal pinacoid** consists of only two faces (0001 and $000\bar{1}$); it is present on some crystals of apatite and beryl (see Fig. 30).

The **unit prism** consists of six faces ($10\bar{1}0$, $01\bar{1}0$, $\bar{1}100$, $\bar{1}010$, $01\bar{1}0$, and $1\bar{1}00$); it occurs on some crystals of apatite in combination with the unit pyramid, as shown in Fig. 28; cross-sections are hexagons.

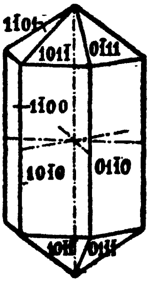

FIG. 28.—Hexagonal prism and pyramid; apatite.

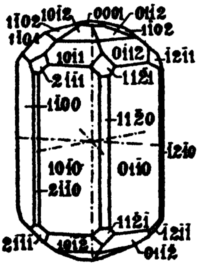

FIG. 29.—Hexagonal prisms, pyramids and base; apatite.

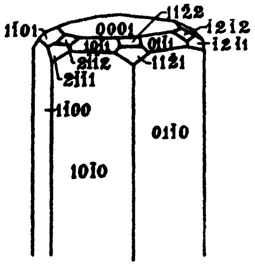

FIG. 30.—Hexagonal prism, base and pyramids; beryl.

The **diametral prism** also consists of six faces ($2\bar{1}\bar{1}0$, $11\bar{2}0$, $\bar{1}2\bar{1}0$, $\bar{2}110$, $\bar{1}\bar{1}20$, and $1\bar{2}10$) which may be developed with or without other vertical faces; in Fig. 29 they truncate the edges of the unit prism, as in some crystals of apatite.

The **dihexagonal** forms are rare and not illustrated here; each face cuts all three horizontal axes at unequal distances.

The **unit pyramid** ($10\bar{1}1$) is present in Fig. 28.

The **diametral pyramid** ($11\bar{2}1$) is shown in Fig. 29 with two unit pyramids ($10\bar{1}1$ and $10\bar{1}2$) the base (0001) and two prisms ($11\bar{2}0$ and $10\bar{1}0$).

Trigonal Division.—All crystals of the trigonal division have a vertical axis of threefold symmetry; the forms of highest grade of symmetry have three auxiliary planes of symmetry normal to the base and bisecting the angles between the lateral crystal axes; they have three axes of twofold symmetry (which coincide with the lateral crystal axes) and a center of symmetry. The special forms of this division include the rhombohedron and the scalenohedron. These forms, alone and in combinations, are illustrated in Figs. 31–36; they are especially common in calcite and quartz.

The **rhombohedron** (Figs. 31, 32) has six faces, each being a rhomb; it has six like lateral edges forming a zigzag around the crystal and six like terminal edges, three above and three below. The vertical axis connects the two trihedral angles; the lateral axes connect the middle points of opposite edges.

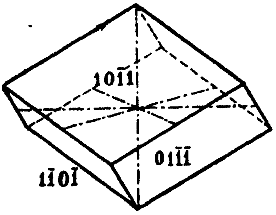

FIG. 31.—Cleavage rhombohedron of calcite, $CaCO_3$.

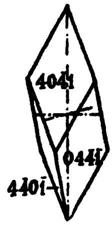

FIG. 32. — Acute rhombohedron of calcite, $CaCO_3$.

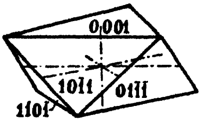

FIG. 33. — Rhombohedron and base; hematite, Fe_2O_3.

The **scalenohedron** (Fig. 34) has twelve faces, each being a scalene triangle. The lateral edges form a zigzag around the crystal just like that around the rhombohedron, but the terminal edges are not all alike.

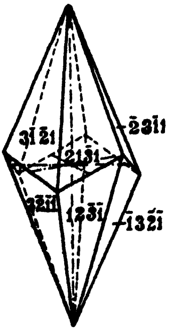

FIG. 34.—Scalenohedron of calcite, $CaCO_3$.

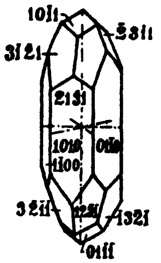

FIG. 35.—Hexagonal prism, scalenohedron and rhombohedron; calcite, $CaCO_3$.

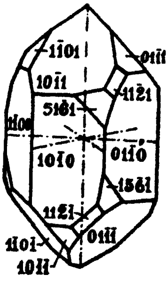

FIG. 36.—Prism and rhombohedrons, modified by right trigonal pyramid right plus trapezohedron. Right-handed quartz, SiO_2.

Orthorhombic System.—All crystals which belong to the orthorhombic system have three unequal rectangular axes, as shown in

Fig. 37. Such crystals[6] have no principal plane of symmetry, but have three axial planes of symmetry, three axes of twofold symmetry (which coincide with the crystal axes) and a center of symmetry. To orient an orthorhombic crystal, that is, to place it in the conventional position, any axis is made vertical and the longer lateral axis, known as the macro-axis, is made to extend right and left. The shorter lateral axis, known as the brachy-axis, then extends from front to rear. A form whose faces are parallel to one of these axes (and not parallel to the other) is named accordingly. Thus, the pinacoid parallel to the brachy-axis is the brachypinacoid.

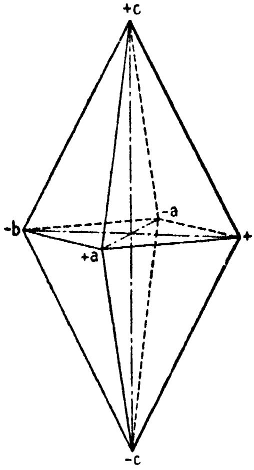

Fig. 37.—Axes within orthorhombic pyramid.

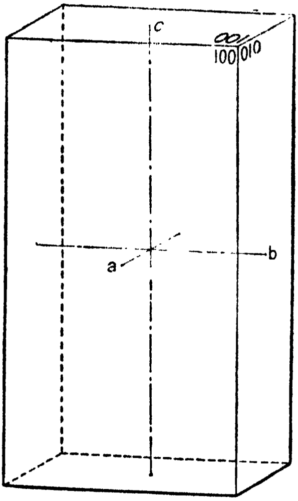

Fig. 38.—Macro-, brachy-, and basal pinacoids.

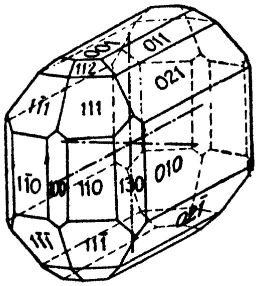

Fig. 39.—A combination of crystal forms in K_2SO_4.

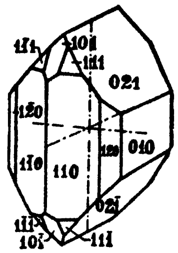

Fig. 40.—A combination of crystal forms in chrysolite.

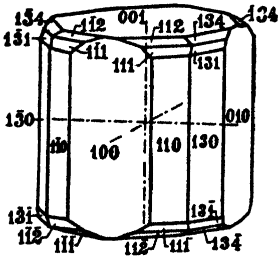

Fig. 41.—A combination of crystal forms in cordierite.

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[6] This refers to crystals of the highest grade of symmetry in the orthorhombic system.

A **dome** is a form each of whose faces is parallel to one lateral axis and cuts the other two axes; therefore, there are brachydomes and macrodomes. Other forms of this system include the base, prism, pyramid and macropinacoid. The three pinacoids are shown in Fig. 38. The unit pyramid is shown in Fig. 37 with the axes. Two different pyramids are illustrated in Fig. 39, a crystal form of K_2SO_4. Both kinds of domes are found in Fig. 40, as seen in chrysolite. The brachyprism (130) and unit prism (110) with the base (001), other pinacoids (100 and 010), and four pyramids, are in combination in Fig. 41, which is a drawing of a common form of natural cordierite. Figs. 42 and 43 illustrate combinations of base, prism and domes occurring in barite crystals.

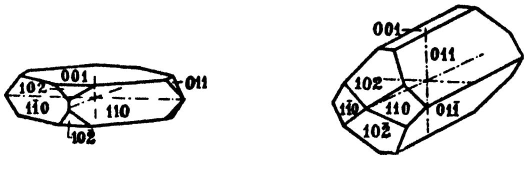


FIG. 42. FIG. 43.

FIGS. 42, 43.—Combinations of crystal forms in barite.

Monoclinic System.—All crystals of the monoclinic system have three unequal axes, one being at right angles to the other two, which are not at right angles to each other, as shown in Fig. 44. The axis which is normal to the other two is called the ortho-axis; one of the other two is the vertical axis (*c*), and the other is called the clino- or inclined axis. To orient the crystal, the ortho-axis (*b*) is made to extend right and left and one of the others is placed vertically; the third axis (*a*) is made to extend downward to the front. A form parallel to one lateral axis, and not parallel to the other, is named from that fact. Therefore, 100 is the orthopinacoid, 010 is the clinopinacoid, 101 is an orthodome, 011 is a clinodome; 130 is similarly called a clinoprism, since it is more nearly parallel with the clino-axis than is the unit prism, 110. The other forms of this system include the base (001) (which is not horizontal in the conventional position),

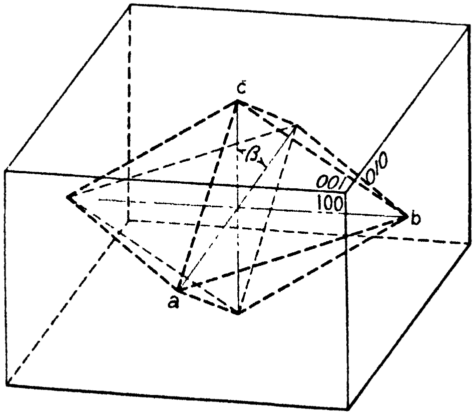


FIG. 44.—Crystal axes and pyramids within pinacoids of a monoclinic crystal.

prism and pyramid. Crystals of maximum symmetry in this system have only one secondary plane of symmetry, one axis of twofold symmetry, and a center of symmetry. Fig. 45 shows a combination of the orthopinacoid (100), clinopinacoid (010), unit prism (110), and unit pyramid (11$\bar{1}$), in augite, which is a ferriferous and aluminous diopside. Fig. 46 shows a combination of the base (001), clinopinacoid (010), unit prism (110), clinoprism (130), orthodome (201), and unit pyramid (11$\bar{1}$), common in orthoclase. Fig. 47 is a crystal habit of $Cs_2Mg(SO_4)_2 \cdot 6H_2O$ consisting of the base (001), prism (110), clinodome (011), orthodome (201), unit pyramid (11$\bar{1}$), and clinopinacoid (010).

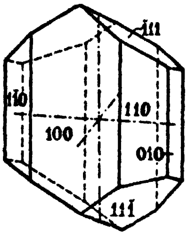


FIG. 45.—Crystal of augite.

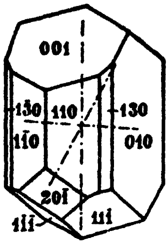


FIG. 46.—Crystal of orthoclase, $KAlSi_3O_8$.

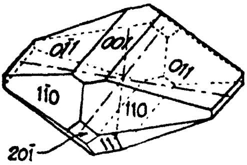


FIG. 47.—A common crystal habit of $Cs_2Mg(SO_4)_2 \cdot 6H_2O$.

Triclinic System.—All crystals of the triclinic system are referred to three unequal axes whose intersections are all oblique, as shown in Fig. 48. To orient the crystal, any axis is placed vertically, the longer lateral axis is made to extend downward to the right and the other downward to the front. The angle between the front and rear axis *a* and the vertical axis *c* is denoted by β (as in the monoclinic

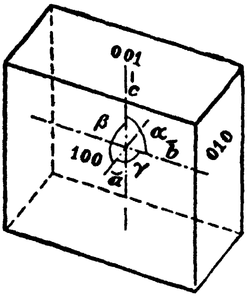


FIG. 48.—Triclinic axes and pinacoids.

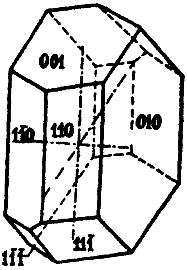


FIG. 49.—Combination of forms in albite.

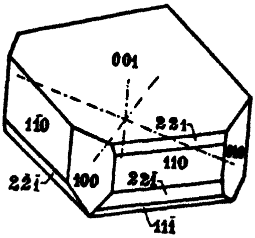


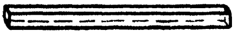
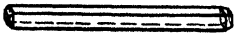
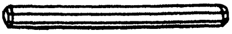
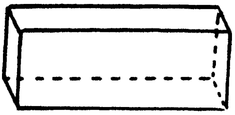
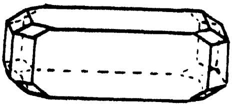
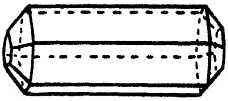
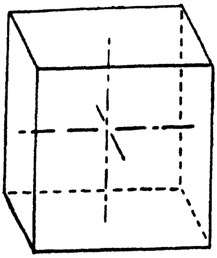
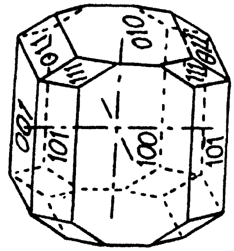
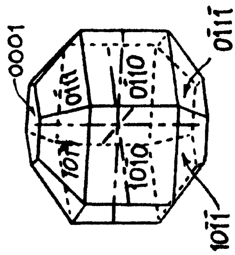
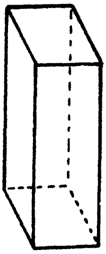
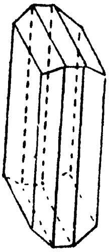
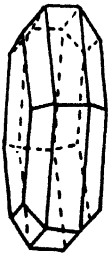
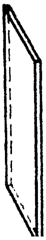
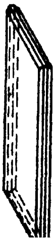
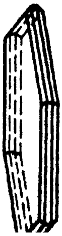
FIG. 50.—Triclinic crystal of rhodonite.

system), that between *a* and *b* is denoted by γ, and that between *b* and *c* by α. Crystals of substances in this system have no plane nor axis of symmetry, but have a center of symmetry. Therefore, each form consists of only two faces, one opposite the other. As in orthorhombic crystals, the longer lateral axis is known as the macro-axis and the shorter as the brachy-axis. Forms are named from parallelism with axes; therefore, 100 is the macropinacoid, 010 the brachypinacoid, 101 a macrodome, and 011 a brachydome. The other forms include the base, prism, and pyramid. Fig. 49 shows a common habit of albite, consisting of a combination of the base (001), the unit prisms (110 and $1\bar{1}0$), the unit pyramids ($11\bar{1}$ and $1\bar{1}\bar{1}$), and the brachypinacoid (010). Fig. 50 illustrates a crystal of rhodonite having a well-developed base (001) with the unit prisms (110 and $1\bar{1}0$), the macropinacoid (100), the brachypinacoid (010) and four pyramids ($11\bar{1}$, $22\bar{1}$, 221, and $2\bar{2}\bar{1}$).

Crystal Habit.—Crystals vary not only in their angular relations and symmetry, but also in their size, the relative development of their faces and the number and kind of faces or forms that are present. Variations in the angular relations of the faces and the symmetry of the forms are of fundamental importance and constitute the chief differences between the six crystal systems just described. Variations in the size of crystals, the relative development of their faces and the number and kind of faces or forms that are present are of no fundamental significance; crystals of any substance always show such variations to some extent, and in some cases these variations produce a great variety in the crystals of one substance. Such variations are said to produce different *crystal habits*. It should be emphasized that variation in crystal habit occurs without the slightest variation in angular relations of the faces and therefore without the slightest variation in the crystallographic symmetry. In spite of the fact that any substance may show two (or even many) crystal habits under varying conditions of formation, many substances so frequently exhibit more or less constancy in crystal habit that a knowledge of their crystal habits is of importance in their study.

The size of artificial crystals depends so largely upon a very exact control of the rate of growth that it is not very important in their study. Nevertheless, crystals of some substances are nearly always small microscopically, while those of other substances are frequently of larger size.

The relative development of the faces and the number and kind of

	ISOMETRIC	TETRAGONAL	HEXAGONAL
ACICULAR	 FIG. 55.	 FIG. 60.	 FIG. 65.
COLUMNAR	 FIG. 54.	 FIG. 59.	 FIG. 64.
EQUANT	 FIG. 53.	 FIG. 58.	 FIG. 63.
TABULAR	 FIG. 52.	 FIG. 57.	 FIG. 62.
LAMELLAR	 FIG. 51.	 FIG. 56.	 FIG. 61.

Orthorhombic

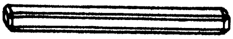


Fig. 70.

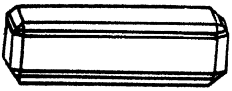


Fig. 69.

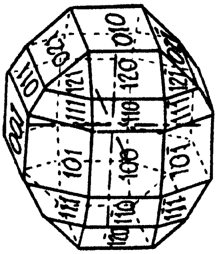


Fig. 68.

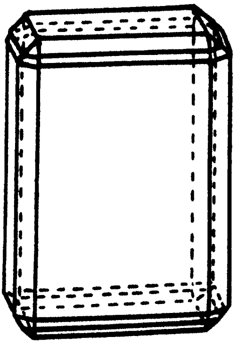


Fig. 67.

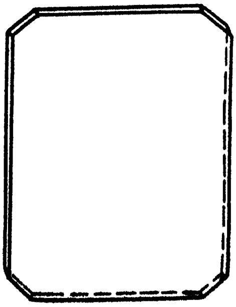


Fig. 66.

Monoclinic

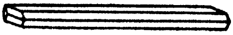


Fig. 75.

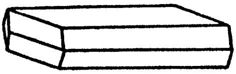


Fig. 74.

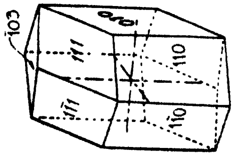


Fig. 73.

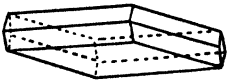


Fig. 72.

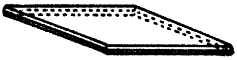


Fig. 71.

Triclinic

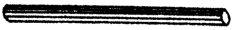


Fig. 80.

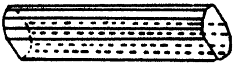


Fig. 79.

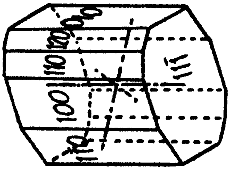


Fig. 78.

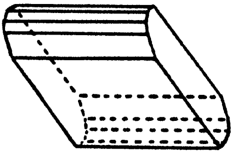


Fig. 77.

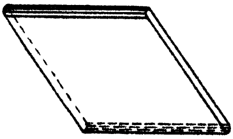


Fig. 76.

faces or forms of crystals vary so greatly when different substances are compared and are so nearly constant in different crystals of one substance in some cases that they furnish data of considerable value in the study of crystals. The relative development of the faces of crystals is one of the chief factors in determining their general shape; if the faces are all of nearly the same size the crystal is likely to be nearly equidimensional, such crystals are said to be *equant*. If a pair of opposite faces are decidedly larger than the other faces, the crystals are necessarily *flattened* and are said to be *tabular*; if this tendency is carried to an extreme they are called *lamellar* or even *foliated*. If three or more faces belonging to one zone, that is, all parallel to any one line, are decidedly larger than the other faces, the crystal is necessarily *elongated* in that direction and is described as *columnar*;[7] if this tendency is carried to an extreme the crystal is described as *acicular* or even *fibrous*. Crystals of any crystal system may be equant, tabular, lamellar, columnar or fibrous, but isometric crystals are usually equant; tetragonal and hexagonal crystals are equant or flattened normal to the vertical axis or elongated parallel thereto; other crystals may be flattened parallel with any pinacoid (or even any other pair of opposite faces) or elongated parallel with any crystal axis (or, rarely, parallel with some other crystal direction).

Crystals which show only one crystal form, or have the faces of one form decidedly larger than those of any other, are easily described as characterized by that form; for example, isometric crystals may be cubic, octahedral, dodecahedral, etc.; tetragonal crystals may be pyramidal, prismatic or pinacoidal; hexagonal crystals may be pyramidal, prismatic, pinacoidal, rhombohedral or scalenohedral; orthorhombic, monoclinic and triclinic crystals may be pyramidal, prismatic, domatic or pinacoidal.

A cubic isometric crystal (Fig. 53) may be flattened to a tabular habit as in Fig. 52; by more flattening it may become lamellar as in Fig. 51, or even foliated; by elongation it may become columnar as in Fig. 54, or even acicular as in Fig. 55. Isometric crystals are usually equant or nearly so. An equant tetragonal crystal of calomel (Hg_2Cl_2) is shown in Fig. 58; this substance often forms crystals of columnar habit as in Fig. 59; acicular crystals (Fig. 60) are not common; tabular crystals (Fig. 57) are not rare in the natural substance, but lamellar crystals (Fig. 56) are very scarce. An equant hexagonal crystal of apatite ($Ca_5FP_3O_{12}$) is shown in Fig. 63; the columnar habit (Fig. 64) is the common one in this substance, but acicular forms (Fig. 65) are not rare; tabular crystals (Fig. 62) and lamellar crystals (Fig. 61) are very rare or unknown in this substance. An equant orthorhombic crystal of olivine [$(Mg,Fe)_2SiO_4$)] is shown in Fig. 68; natural olivine is often tabular parallel to 100 as in Fig. 67, while natural iron olivine or fayalite is likely to be lamellar in that direction as in Fig. 66; the columnar habit (Fig. 69) is found in magnesian olivine or forsterite; the acicular habit (Fig. 70) is unknown or rare in olivine. Fig. 73 shows an equant monoclinic crystal of gypsum, ($CaSO_4 \cdot 2H_2O$); such crystals are often tabular parallel to 010 as in Fig. 72; the lamellar habit (Fig. 71) is less common; a columnar habit (Fig. 74) is shown by crystals formed in a $MgCl_2$ solution; a fibrous habit (Fig. 75) is also known in the natural mineral. An equant triclinic crystal of chalcanthite[8] ($CuSO_4 \cdot 5H_2O$) is illustrated in Fig. 78; such crystals are often columnar as in Fig. 79, or even fibrous as in Fig. 80; when formed artificially on a glass slide they are tabular to lamellar lying on 110 as shown in Figs. 76 and 77.

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[7] Some writers describe columnar and acicular crystals as prismatic; this is correct geometrically, but incorrect crystallographically unless the long faces are prisms; they may be domes or pinacoids or even pyramids.

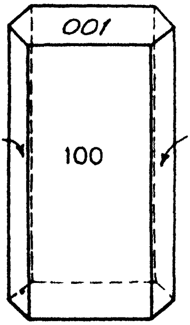
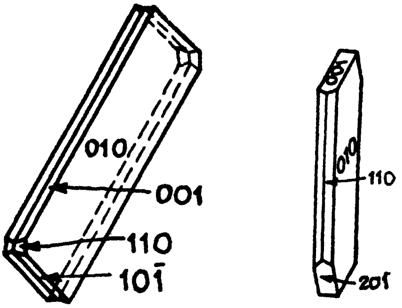


FIG. 81.—A bladed crystal of kyanite, Al_2SiO_5



FIGS. 82, 82a.—Lath-shaped crystals of feldspar.

Crystals which are much flattened or much elongated tend to be simpler, that is, have fewer faces, than corresponding equant crystals; this tendency is illustrated in Figs. 56, 57 and 60 as compared with Fig. 58, Figs. 66 and 70 as compared with Fig. 68, and Figs. 76 and 80 as compared with Fig. 78.

Some crystals show both elongation and flattening; such crystals are described as *bladed* if developed as in Fig. 81 or *lath-shaped* if similar to Figs. 82 or 82*a* in development.

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[8] The orientation differs from that of Tutton and Barker by reversing the *c* axis so as to make the *b* axis incline downward to the *right*, as usual in triclinic crystals.

Crystal aggregates.—Crystals frequently grow in groups or aggregates in which the various crystals show more or less tendency to parallelism. In case all the axes of one are parallel to corresponding axes in the other, the aggregate is called a parallel growth. Such growths may consist of many crystals, rather than merely two, and then the grouping is apt to be such as to form the axes (or other chief parts) of a much larger crystal of the same kind. Such skeleton crystals may continue to grow and fill out to form one large crystal. Snowflakes are excellent examples of skeleton crystals. When a flake fills out, it forms one hexagonal crystal of ice.

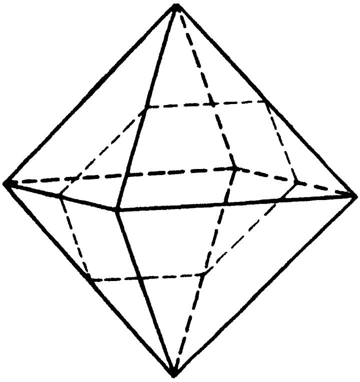

FIG. 83.—Simple octahedron of spinel.

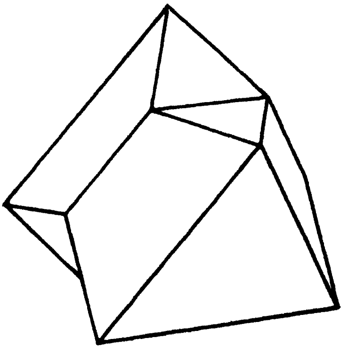

FIG. 84.—Spinel octahedron in twinning position.

Twins.—Crystals of a single species also frequently grow in positions in which the parallelism of the parts is incomplete; that is, some corresponding directions are exactly parallel and others are not. Two crystals of the same kind, which form an aggregate exhibiting such partial parallelism, are called a twin, or are said to be in twinning position. The relative position of two crystals in twinning position may be most readily understood by *assuming* that one has been revolved through 180° about some direction or axis, which thus remains common to both. Thus, in Fig. 83, a crystal, say of spinel, forms a simple octahedron. If this octahedron be supposed to be cut in two parts along the dotted plane parallel to an octahedral face and the lower half be supposed to be revolved through 180° about an axis normal to this plane, the twinned form of Fig. 84 is produced. It should be emphasized that twins are not produced by such a revolution, but by regular growth (except the secondary twins produced by shearing, etc.); this is merely a convenient way to describe the relative positions.

The axis about which one part is supposed to be revolved is called the twinning axis, and the plane normal to this is the twinning plane. The plane by which twinned crystals are united is called the composition plane. This is often the same as the twinning plane, but it is not necessarily so; when it is not the same as the twinning plane, the composition plane is apt to be parallel with the twinning axis, as in Carlsbad twins of feldspar (see Fig. 93). The twinning axis is nearly always a crystal axis or normal to a possible crystal face. If twins are simply adherent by the composition face, they are contact twins; if they interpenetrate more or less, they commonly have an irregular composition surface and are called penetration twins, as illustrated in Fig. 94. In many cases twins are composed of more than two parts, the mutual relations of any two adjacent parts being the same. In this case the twinning is described as multiple or polysynthetic, if the composition faces are parallel, and cyclic or symmetrical, if the composition faces are not parallel but related like adjacent faces of a prism so that the twinned parts tend to turn in a circle. Repeated twinning of the cyclic type often gives rise to an apparent symmetry, called pseudosymmetry, greater than that actually possessed by the crystal. Thus, orthorhombic cordierite may seem to be hexagonal on account of cyclic twinning.

Twinning may be produced artificially, in some cases, by shearing or other stresses; such twinning is called secondary. It is illustrated by some twinning in calcite (Fig. 88) and by some multiple twinning in feldspar and pyroxene.

Common twinning laws.—The most important type of twinning, in crystals of the isometric system, is that illustrated in Fig. 84; this, like all other types of twinning, is most conveniently described by stating the crystallographic position of the twinning axis or the twinning plane, and such a statement is known as a twinning law. Twins whose twinning axis is normal to an octahedral face, as in Fig. 84, are especially common in spinel and are therefore known as spinel twins; they may be either contact twins, or penetration forms, as illustrated by Fig. 85 for $NaClO_3$, and by Fig. 86 for fluorite.

In the tetragonal system, the most important type of twinning is that which corresponds to the spinel law, but in this case the twinning axis is normal to the face of a pyramid. Such twins are especially common in rutile and cassiterite; when simple they are described as geniculated, or knee-shaped, as in Fig. 87.

In the hexagonal system, twins are rare and unimportant in crystals of the hexagonal division, but are common in those of the trigonal division. The calcite crystals and anhedra in rocks often show twinning lamellæ (twinned on $01\bar{1}2$), which may be of secondary origin, as shown by the fact that a single cleavage piece of calcite may be changed, in part, into a twin, by pressure with a dull knife on an obtuse edge of a piece of prismatic form, the other obtuse edge resting on a firm support. This is illustrated in Fig. 88; the portion moved (that is, *abcd* to *a'b'cd*) takes a position as if twinned on $01\bar{1}2$ (or *edc*); it is not broken off, but is in a new position of stability.

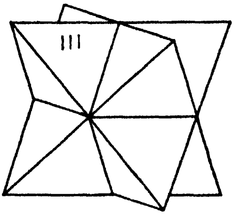

FIG. 85.—Two tetrahedrons interpenetrating in twinning position, as in $NaClO_3$.

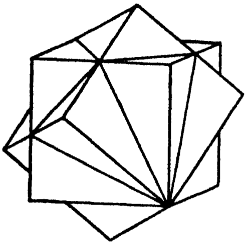

FIG. 86.—Two cubes interpenetrating in twinning position, as in CaF_2.

In the orthorhombic system the commonest type of twinning has the twinning axis normal to the face of a prism whose prismatic angle is about 60°. This is well illustrated in aragonite and in cordierite, as shown in Figs. 89 and 90 of aragonite, and 91 of cordierite.

Twinning is more important in the monoclinic system. The commonest type has the vertical axis as the twinning axis, as illustrated by Fig. 92 for gypsum. The same law gives the groups called Carlsbad twins in feldspar, which are either contact forms or penetration twins, as shown in Figs. 93 and 94. This type of twinning may be explained equally well by referring it to the orthopinacoid, 100, as the twinning plane. In Baveno twins of orthoclase the twinning plane is the clinodome, 021, and since the angle between this face and the base is 44° 56′, nearly square forms result, as illustrated in Fig. 95; they are commonly elongated parallel to the *a* axis. A rare type of twinning in ortho-

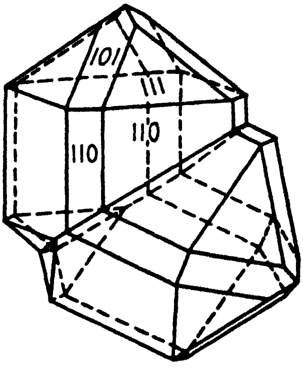

FIG. 87.—Geniculated twin in cassiterite, SnO_2.

clase is known as the Manebach, in which the basal plane is the twinning plane and also the composition face, as shown in Fig. 96.

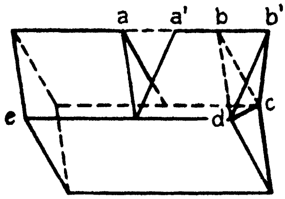

FIG. 88.—Artificial twin produced in calcite, $CaCO_3$.

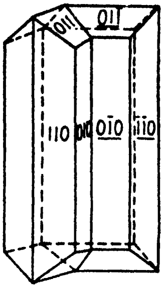

FIG. 89.—Aragonite ($CaCO_3$) twinned on 110.

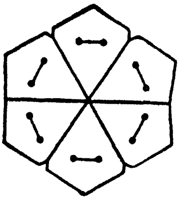

FIG. 90.—Cross-section of pseudohexagonal cyclic twin of aragonite, $CaCO_3$.

The twinning peculiar to triclinic feldspar is of several types, the more abundant being the albite and pericline. The former type has 010 as the twinning plane, the latter has the *b* axis as the twinning axis. Both types are nearly always polysynthetic, producing narrow lamellæ which are parallel to 010 in albite twinning and parallel to the axis *b* in pericline twinning. Therefore, albite twinning produces fine striations on a basal cleavage surface and pericline twinning produces similar striations on the brachypinacoidal cleavage or face. A simple albite twin is shown in Fig. 97; this type of twinning is nearly always present, and many times repeated, in all kinds of plagioclase, and thus produces striations on the base parallel to 010, as illustrated in Fig. 99. A simple pericline twin is represented in Fig. 98; in such twins the composition plane passes through the crystal in such a direction that its intersections with the prismatic faces make an equilateral oblique-angled parallelogram or rhombus.

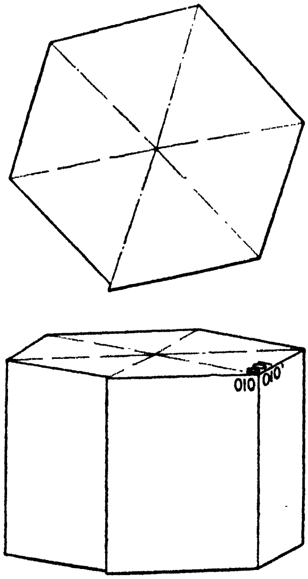

FIG. 91.—Pseudohexagonal cyclic twin of cordierite.

Hitherto, aggregates have been described in which all the crystals are of one kind of species. Aggregates of crystals of two (or more) kinds may show similar relations in position. Thus, aggregates of isomorphous crystals (that is, crystals chemically and crystallographically similar, but not identical) may be in almost completely parallel positions as illustrated in the zonal growths of alum and in those of feldspar; twinning may extend continuously through such zones.

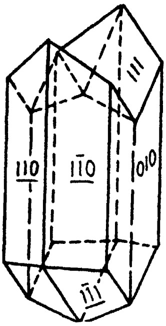

FIG. 92.—Gypsum ($CaSO_4 \cdot 2H_2O$) twinned on vertical axis.

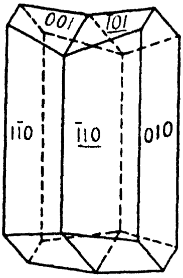

FIG. 93.—Contact Carlsbad twin of albite, $NaAlSi_3O_8$.

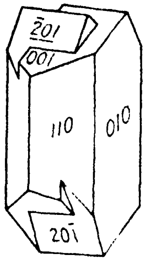

FIG. 94.—Partial penetration Carlsbad twin of orthoclase, $KAlSi_3O_8$.

The zones are usually bounded by planes which were once crystal faces, each zone representing a period of additional growth of the crystal. The composition of the zones varies, often in regular sequence or progression; thus, in plagioclase of igneous rocks, the zones commonly are progressively richer in albite from the center outward.

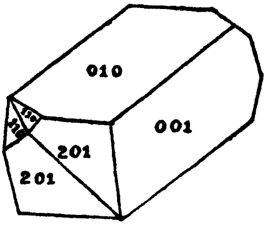

FIG. 95.—Baveno twin of orthoclase, $KAlSi_3O_8$.

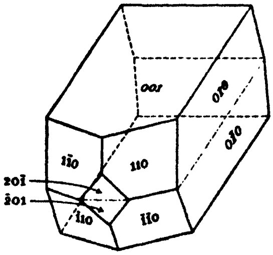

FIG. 96.—Manebach twin of orthoclase, $KAlSi_3O_8$.

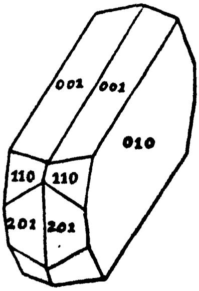

FIG. 97.—Simple albite twin in plagioclase.

Aggregates of crystals which are wholly unlike, chemically and crystallographically, usually show no definite relations in their mutual positions, but even in this case definite relations are sometimes found. Thus, quartz has been observed growing in parallel position on rhombohedral faces of calcite, rutile may develop in three directions parallel to prominent edges on the basal plane of mica, etc. But in such aggregates one mineral is apt to be completely enclosed by another.

Inclusions.—Any substance completely enclosed by another is known as an inclusion, no matter what its nature or origin may be. Accordingly, inclusions may be gaseous, liquid, or solid. If they originate at the time of formation of the enclosing crystal, they are called primary; if they originate by alteration or introduction after the formation of the enclosing crystal, they are called secondary. A crystal which grows very rapidly may shoot out in various chief directions like frost of one orientation on a window pane, and then the skeleton form may be filled in during a period of slow growth. In such cases, deeply reentrant angles may be filled with foreign material which is finally completely surrounded by the growth of the crystal. If the enclosed material is a liquid, it may contract, upon cooling, so that it no longer fills the whole space; the cavity will then be occupied by a liquid and its gas. Or, the enclosed liquid may consist of parts immiscible at ordinary temperatures, so that the cavity may contain two liquids and a gas, as illustrated by cavities in quartz containing water, liquid carbon dioxide, and gas. The nature of the liquid is determinable, in some cases, by measuring its index of refraction, by determining its critical point, or by chemical tests. In many cases the liquid is water or carbon dioxide, or a solution in which the crystals grew.

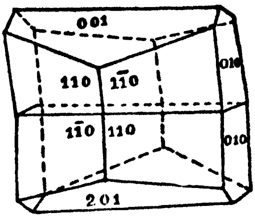

FIG. 98.—Simple pericline twin in albite, $NaAlSi_3O_8$.

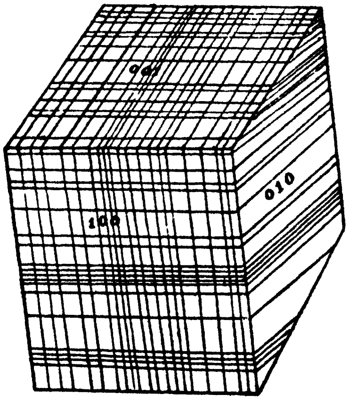

FIG. 99.—External albite and pericline striations in albite, $NaAlSi_3O_8$.

When the enclosed liquid contains molecules of the enclosing crystal in solution these may crystallize on the walls of the cavity during cooling, and thus give it crystal faces. The cavity is then called a negative crystal; such forms are common in quartz and halite. Such negative crystals probably may be produced also by simple growth of the enclosing crystal. Sufficient growth of the halite to cover one side of a hollow cube is all that is necessary to change the deep reentrant cubic spaces on crystals of halite into negative cubic crystals.

When crystals of other substances are present in a liquid, they may be enclosed by another growing crystal. This may happen with or without evidence that the growing crystal moves the other. The concentration of enclosed crystals in certain zones in leucite and feldspar is probably due to their being thrust aside for a time by the growing crystal, until more rapid growth results in their being surrounded. In other cases, inclusions are arranged radially; Pirsson has shown how this condition may result from progressive growth from skeletal forms, as illustrated in Fig. 100.

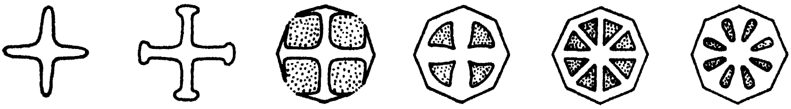

FIG. 100.—Radial inclusions in leucite ($KAlSi_2O_6$) resulting from development of skeletal forms. (After Pirsson.)

The physical characters of crystals which relate to their effects on light will be described in detail in later sections of this book. The other physical characters, aside from crystallization, will be briefly summarized here, with special reference to their use in optical study with the microscope.

Cleavage is the property of some crystals to break along definite smooth planes, which are called cleavage planes, and are always possible crystal faces, since they are determined by the regular internal arrangement of the atoms. Cleavages (like crystal faces) occur parallel with planes in which the atoms are closely packed together, and normal to which the distance between adjacent layers of atoms is relatively great. Cleavage is described, according to its crystallographic direction, as cubic, octahedral, rhombohedral, basal, prismatic, etc. It is also described, according to the ease with which it is obtained and the smoothness of the surfaces produced, as perfect or eminent, distinct, indistinct or imperfect, and difficult. Cleavage is perfect when it is obtained with great ease and yields smooth, lustrous surfaces, as in mica, calcite, etc. The other terms express inferior degrees of cleavage.

In all directions, in a crystal, which are crystallographically the same, cleavage is the same in quality; conversely, if the crystallography of a given substance is unknown, the cleavage provides a means by which equivalent crystal directions may be recognized. A single cleavage, crystallographically, may exist in a crystal in one, two, three, four, or even six different directions; thus, $NiSO_4 \cdot 6H_2O$ has basal cleavage in only one direction; enstatite and diopside have prismatic cleavage in two directions parallel to the prism faces; calcite has rhombohedral cleavage in three directions; fluorite has octahedral cleavage in four directions; and garnet may have *parting* (similar to cleavage, but secondarily developed by strain and not always present) in six directions parallel to dodecahedral faces. Sphalerite has cleavage in these directions.

Also, a crystal may have only one cleavage, or two, or even more cleavages crystallographically unlike; they are then unlike in quality. Thus, picromerite [$(K_2Mg(SO_4)_2 \cdot 6H_2O)$] has only one perfect cleavage, which is parallel to the dome ($20\bar{1}$); orthoclase has two cleavages parallel to two of the pinacoids (001 and 010); and anhydrite has three pinacoidal cleavages.

In thin sections of crystals, cleavage is seen as one or more sets of more or less narrow, straight and parallel cracks, which are continuous or interrupted (and perhaps offset), according to the quality of the cleavage. These cracks are unquestionably developed in part during the grinding of the section, but in part they are present independent of the grinding. Sections of varying orientation through a single crystal may not show the same abundance of cleavages; those cut about at right angles to the cleavage planes commonly show them more abundantly than others cut nearly parallel with these planes. For example, a simple crystal of hornblende, like Fig. 101, will show its prismatic cleavages well developed in two sets of narrow, straight, parallel cracks, forming an angle of 124° in a cross-section which is normal to both cleavage planes, as in Fig. 104. In a section parallel to the clinopinacoid (010) the cleavage cracks are not so numerous nor so closely spaced, and they are apt to be discontinuous, as in Fig. 102. The traces of these cleavages are parallel, but the planes of the cleavages are not parallel, being inclined in two directions, making angles of 62° with the plane of the section. In a section parallel to the orthopinacoid, cleavage cracks are still less abundant, and, in fact, may be entirely lacking, or, at least, invisible. If present, as in Fig. 103, they are likely to be widely spaced, discontinuous, and rather indistinct; their traces are parallel, but their planes are inclined in two directions, making angles of 28° with the plane of the section.

Cleavages in section are more easily seen in crystals of higher index of refraction, because this results in more reflection and refraction along the cleavage plane. For a similar reason, cleavages may be less distinct, because apparently narrower, in sections normal to the cleavage planes than in others varying somewhat from this direction. The relation of the plane of cleavage to the plane of the section may be learned in an approximate way by focusing a high power objective first on the upper edge of the cleavage crack and then on the lower edge, and noting whether the image shifts to one side or the other or remains stationary. In the latter case the cleavage plane is normal to the plane of the section.

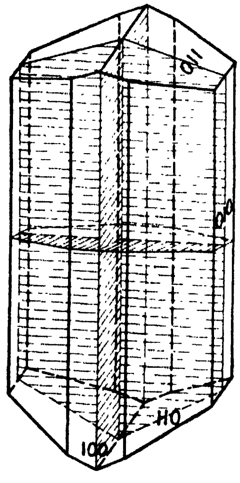

Fig. 101.—Simple crystal of hornblende.

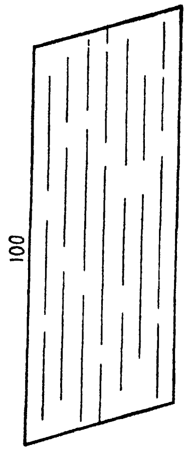

Fig. 102.—Clinopinacoid section of hornblende crystal.

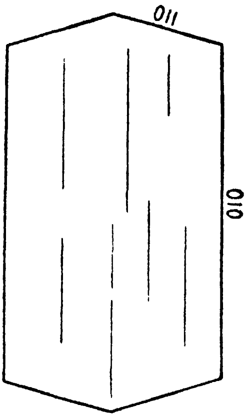

Fig. 103.—Orthopinacoid section of hornblende crystal.

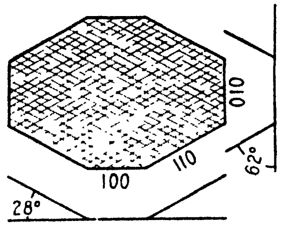

Fig. 104. — Cross-section of hornblende crystal.

The development of cleavage cracks depends, in some cases, upon the magnitude of the stresses produced in a crystal (for example, during grinding) in comparison with its cohesion. The stresses are naturally less in tiny crystals than in large ones; so it happens that small crystals of enstatite may be quite devoid of cleavage cracks in thin section, though larger crystals show them plainly.

Cleavage is very useful in the microscopic study of crystals, as will be evident from its applications in the later portion of this book.

Fracture.—Crystals which have no cleavage are said to fracture rather than to cleave. Further, the break of a cleavable crystal in any direction other than that of the cleavage is also fracture. Fracture differs from cleavage in being more or less irregular, uneven, or curved, and in no definite crystal direction. Fracture is described as conchoidal when the surfaces produced are smooth and curved, often concave, like those of some shells. It is described as uneven when the surface, though rough with many small irregularities, is approximately a plane.

Hardness is a term ordinarily used with a rather vague meaning; as applied to crystals it refers to the resistance offered to the production of a scratch on a smooth surface. In minerals there are all grades of hardness, from that of talc, easily scratched with the fingernail, to that of the diamond, which is the hardest substance known, either natural or artificial. Hardness (H) is always expressed in terms of the scale devised by Mohs, which is as follows:[9] 1. Talc; 2. Gypsum; 3. Calcite; 4. Fluorite; 5. Apatite; 6. Orthoclase; 7. Quartz; 8. Topaz; 9. Corundum; 10. Diamond.

A crystal which scratches and also is scratched by one of the minerals of this scale has the same hardness as that mineral. A crystal which scratches one of the scale, as fluorite, but not the next higher (being scratched by that) has an intermediate hardness, commonly expressed by the lower number with a fraction—in this case the hardness would be four and a half, or H. = 4.5. In testing hardness it is important to distinguish between a scratch and a chalk mark; the latter is easily rubbed off; the former is not.

Hardness is of little importance in the microscopic study of crystals, but it is an important factor in the preparation of thin sections, in determining the smoothness or polish attained. Hard crystals are likely to be left slightly thicker than soft ones and may have scratches unremoved by the polishing with the finer powders. Also, the soft crystals may be torn or pitted or even bent by the coarse grinding; this is illustrated on a small scale by the waviness or crinkling so common in micas in thin sections.

Specific gravity. — The specific gravity of a crystal is the numerical ratio between its weight and the weight of an equal volume of water. Specific gravity is a definite characteristic which does not vary (at given temperature and pressure) so long as the composition of the crystal does not vary. The specific gravity may be determined by weighing a substance in air and then weighing it when suspended in water; the loss of weight in water is equal to the weight of an equal volume of water. The second weighing may be replaced by a measurement of the volume of the substance, as by immersion in a burette, since 1 c.c. of water weighs 1 gm. In measuring specific gravity it is important to obtain pure material and remove all the air from the fragments, under an exhaust-pump. Indirect methods of measuring specific gravity by comparison with that of liquids are of special importance, because they also furnish methods of separating powders into their constituent crystal components. Several moderately heavy liquids are known. By dilution with an appropriate liquid, the density of these liquids may be lowered at will to any desired extent, and thus made equal to that of any crystal (not too heavy) whose specific gravity is to be determined. This condition of equality is easily recognized by the fact that the crystal stays indefinitely in any part of the liquid, neither rising nor sinking. The specific gravity of the liquid (and therefore of the crystal) may then be quickly determined by the use of the Westphal balance, shown in Fig. 105. By hanging suitable weights on the long arm at the end, or at a decimal division, until the sinker remains suspended in the liquid and the balance is in equilibrium, the specific gravity may be read from the number, kind, and position of the weights. Heavy liquids are used to separate the powdered crystal aggregates; when the

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[9] Recent work indicates that fluorite and apatite are nearly alike in hardness, and that topaz is only a little harder than quartz. See A. Rosiwal: *Mitt. Wiener Min. Gesell.*, 1917, No. 80, p. 69; issued with *T.M.P.M.*, 1917, vol. 39; and P. J. Holmquist: *Geol. För. Förh.*, Stockholm, vol. 38, p. 501.

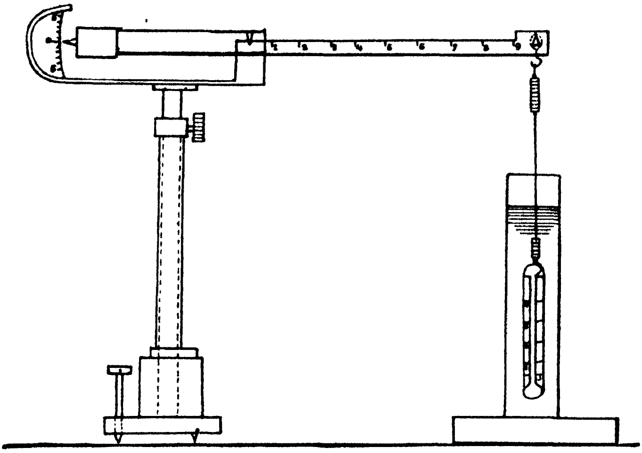

FIG. 105.—Westphal balance.

powder is put into the liquid, the heaviest crystals will sink to the bottom and others will rise to the top. Those on top may be decanted off, or otherwise removed, and the process repeated with a lighter liquid. The process of settling is very slow with fine powders; it may be hastened by removing the air from the powder by means of suction from a vacuum pump. It may be expedited much more by the use of a centrifuge. The most important " heavy solutions " for measuring specific gravity or separating powders are Thoulet's solution, methylene iodide, and Clerici's solution. A cheaper substitute for these is s-tetrabromoethane.

Thoulet's solution is a very poisonous solution of iodide of potassium and mercury, which may be readily prepared by heating 270 gm. of mercuric iodide and 230 gm. of potassium iodide in 80 c.c. of distilled water in a porcelain evaporating dish on a water-bath. After a little evaporation, a crystal of fluorite (G. =3.18) will float on the liquid, or a crystalline film will form on the surface. Upon cooling, the density reaches about 3.10; the liquid should be transparent and of a yellowish green color; it is stable, provided a few drops of mercury are added; otherwise, iodine slowly separates and darkens the color. It may be diluted with water in any proportions and subsequently reconcentrated by evaporation.

Methylene iodide is a thin, light-yellow fluid of high refractive index and maximum density of about 3.3, which cannot be diluted with water or alcohol (which spoil it), but mixes in all proportions with benzol or ether. It is moderately stable in air, and slowly darkens in sunlight; a drop of mercury retards the darkening. It is so mobile that very fine powders may be separated—much finer than can be used in Thoulet's solution. The cleaning of the recovered powder is very simple, being accomplished by washing with benzol. Methylene iodide may be used in separating minerals which are soluble in water. It is quite expensive.

s-Tetrabromoethane has a maximum density of 3.0; it may be diluted with benzol, ether or toluol, and restored to the maximum by evaporation. It is not decomposed by ordinary inorganic crystals, not even by sulphide crystals. For crystals of specific gravity below 3 it is widely used, being cheap, convenient to use and constant in physical characteristics.

Clerici's solution[10] is a mutual solution of thallium malonate,

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[10] *Rend. Accad. Lincei, Roma,* XVI, 1907, p. 187 and XXXI, 1922, p. 116; see also H. E. Vassar: *Am. Mineral,* X, 1925, p. 123.

$CH_2(COOTl)_2$ and thallium formate, HCOOTl, which is remarkable for its high density of 4.25 at ordinary temperature and about 4.65 at 50° C. It may be diluted with water in any quantity and reconcentrated by evaporation. It is more mobile than Thoulet's solution, odorless and slightly amber colored. At ordinary temperature the solution is quite stable; it is able to attack sulphides when heated. It may be prepared by dissolving the dry salts in water; 7 gm. of each will dissolve completely in 1 c.c. of water. It is quite expensive, but the high density and convenience of use make it indispensable for some purposes.

Fusibility.—Most crystals melt at high temperatures; the relative temperatures of melting determine their fusibility. The approximate relative fusibility is usually expressed in terms of the following scale:

SCALE OF FUSIBILITY

Number	Mineral	Approximate Fusing Point	Notes
1	Stibnite	525° C.	Fuses easily in a candle flame
2	Chalcopyrite	800° C.	Fuses slowly in a gas flame
3	Almandite	1050° C.	Only finest splinters rounded in a gas flame
4	Actinolite	1200° C.	Standard-size fragments are rounded easily before the blowpipe
5	Orthoclase	1300° C.	Standard-size fragments are rounded with difficulty before the blowpipe
6	Bronzite	1400° C.	Only finest splinters rounded on points with difficulty before the blowpipe
7	Quartz	Above 1400° C.	Entirely infusible before the blowpipe

A fragment of standard size is 1.5 mm. in diameter.

A crystal which melts more easily than actinolite and less easily than almandite is said to have a fusibility of three and a half, or, in brief, F. = 3.5.

Fusibility is rarely employed in the microscopic study of crystals, but grains of powders may readily be tested in this way.

Electrical conductivity is of some importance, because the development of electrostatic charges depends upon it. Most crystals are very poor conductors of the electric current, but strictly opaque crystals are commonly good conductors. Electrostatic charges may be produced, under suitable conditions, in good conductors, which may thus be separated from bad conductors. For example, if a mixture of ilmenite and monazite, or of pyrite and quartz or calcite, is placed on a good conducting surface, such as a copper plate, and dried thoroughly, and a flattened stick of sealing wax, which has been previously excited by rubbing, is brought near, grains of the former mineral (in each case) will be attracted to the sealing wax, and may be thus entirely separated. The method may be applied to rock and ore powders.

Magnetism in crystals varies very greatly. A few minerals in their natural state are attracted by a strong steel magnet; they are said to be magnetic; the only common mineral exhibiting this property is called magnetite because of it. Some other minerals show the same property in less and variable degree; these include hematite and pyrrhotite. But in a very strong electric field, like that between the poles of a powerful electromagnet, all crystals are influenced by the magnetic force. If they are attracted to the poles they are called paramagnetic; if they are repelled they are called diamagnetic. Most crystals which contain iron are paramagnetic; diamagnetic crystals include calcite, quartz, and apatite. This method is in use in the separation of ore minerals from gangue and is of value in separating powders.

CHAPTER II

APPARATUS AND PREPARATION OF MATERIAL

Microscopes.—As an optical instrument, a microscope is merely a set of lenses arranged so as to produce an image larger than the object. The most distinctive feature of a polarizing microscope is the device for changing ordinary light into light vibrating in a single plane. Every polarizing microscope has at least two such devices, called Nicol prisms, or simply nicols, one being placed between the mirror and the condenser and the other above the objective. Both nicols can be removed from the path of light, if desired, and, in some microscopes, they can be rotated singly or together. The essential quality of these nicols consists in their power to eliminate one ray and allow the passage of the other, vibrating in only one plane.

For nearly all preliminary work the objective of low magnifying power is most suitable. It is the one of longest focus and largest lower glass lens.

In order to avoid the possibility of crushing the object, the microscope should always be focused by lowering the tube while observing it from the side, and then raising it to its focus while looking through the instrument.

The magnification[1] produced by the microscope is the product of that caused by the objective and that effected by the ocular. By observing a scale of small divisions (called a micrometer) etched on glass and placed on the stage of the microscope, through the ocular which contains a similar scale in its focal plane (F_2 in Fig. 106), it is possible to measure the magnification produced by each objective, and also to determine the relative value of the smallest divisions in the ocular micrometer with each objective, so that these divisions can be used to measure other objects.

A polarizing microscope, made by Swift, of London, is illustrated in Fig. 107. One of the unusual features is the absence of a rotating stage; angular measurements of extinction angles, etc., are made by rotating the nicols instead of the stage. This arrangement obviates the necessity of recentering objectives after each change. The substage arrangement is especially convenient, as three condensers of varying power are provided, and are easily interchangeable; the possibility of using an oil immersion condenser with a large angle objective and no rotation of the stage renders this microscope particularly valuable in the examination of small mineral grains and powders.

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[1] It also varies with the tube length and depends upon the distance of distinct vision of the observer's eye.

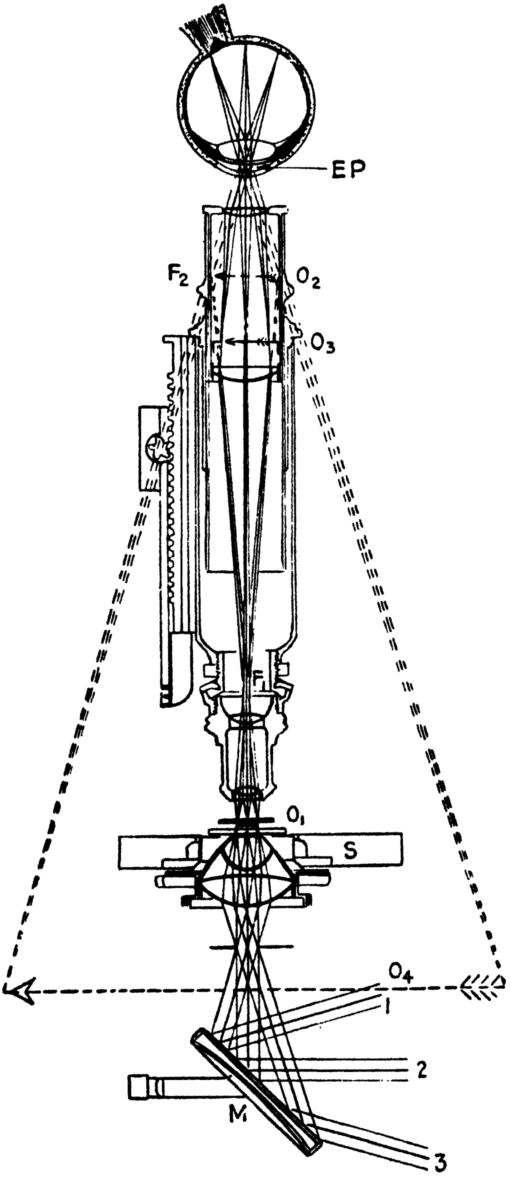

FIG. 106.—The path of light in a microscope.

A polarizing microscope which is remarkable on account of the excellence of its mechanical construction is made by Winkel.[2] In this instrument special provision is made for securing clear interference figures even from very small crystals. It is also equipped with a revolving nose-piece, which permits rapid changing of the objectives and makes recentering unnecessary; it is not even necessary to refocus (except with the fine adjustment) when changing from the low to intermediate power, or *vice versa*. This microscope, shown in Fig. 108, has ample working distance to permit the use of the universal stage.

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[2] Göttingen, Germany; these "Winkel-Zeiss" microscopes are sold by C. Zeiss of Jena, Germany.

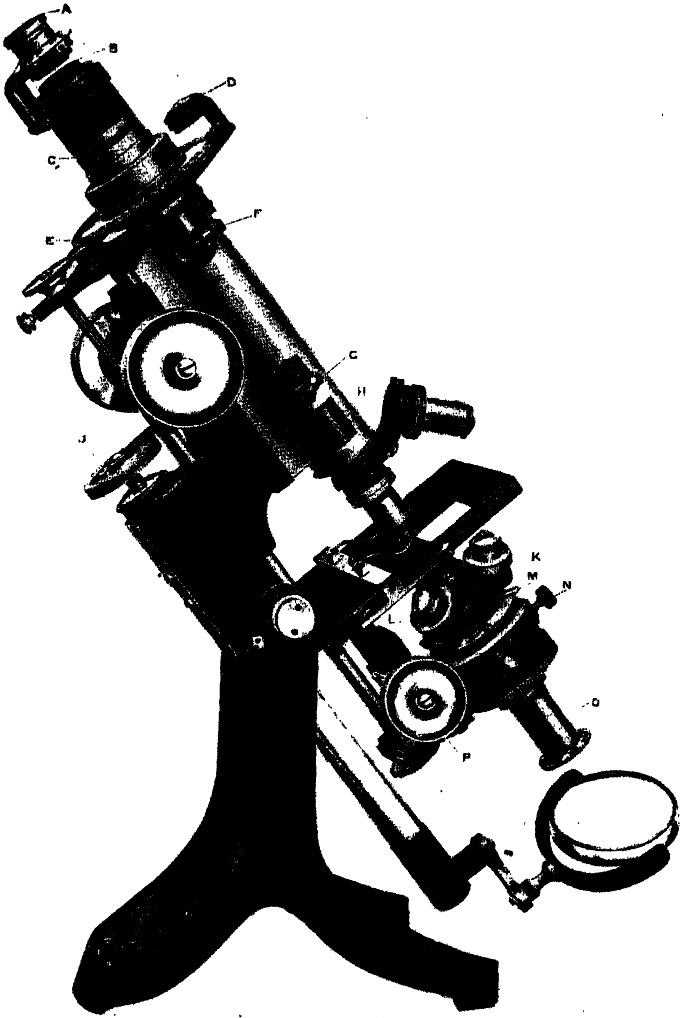

FIG. 107.—A polarizing microscope made by Swift.

A recent type of microscope made by Leitz[3] is illustrated in Fig. 109. In this model the nicols may be rotated together through an angle of 240°, and during rotation the analyzer and Bertrand lens may be removed or inserted at any position. The cross hairs of the ocular remain parallel with the vibration planes of the nicols at all positions of rotation. It is equipped with a special clutch and objective adapters which make recentering unnecessary. It is designed with special reference to the use of the Fedoroff universal stage.

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[3] Wetzlar, Germany.

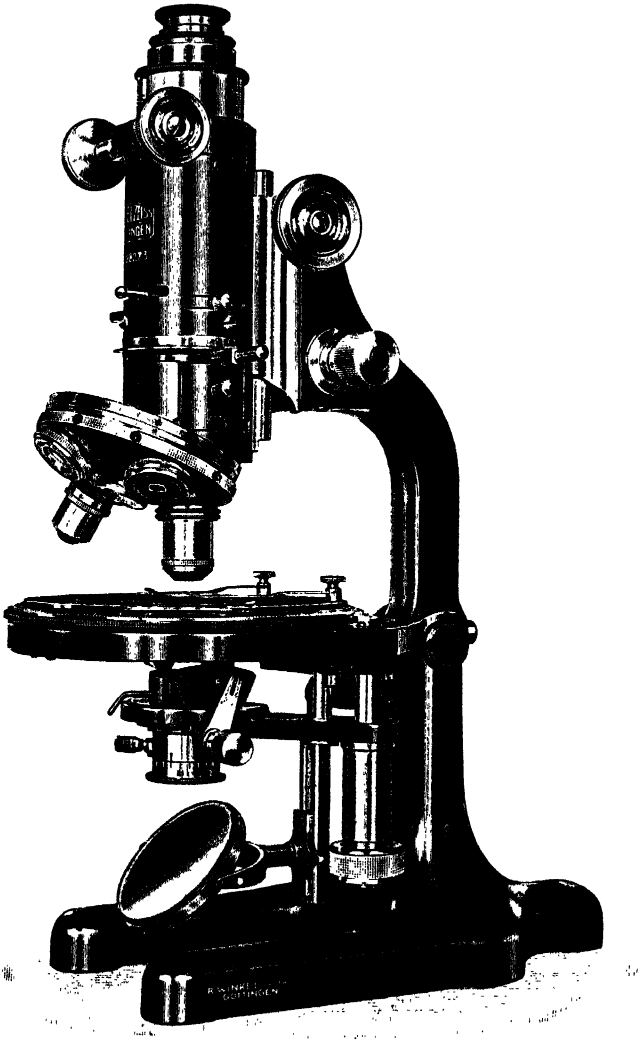

Fig. 108.—A Winkel-Zeiss polarizing microscope.

The only polarizing microscopes made in America for laboratory use are those of Bausch & Lomb, of Rochester, N. Y., one type of which is illustrated in Fig. 110. In this model the condenser may be lowered or thrown out of the optical system; the upper nicol slides in or out of

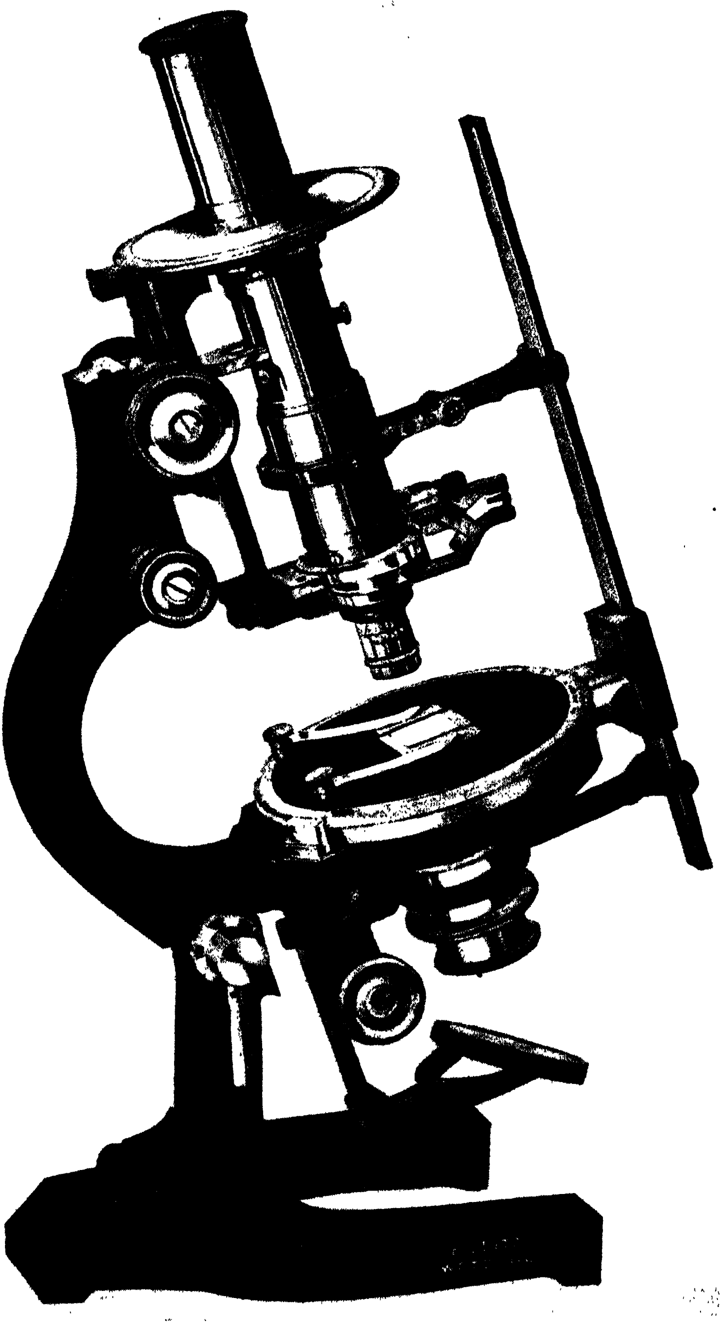

FIG. 109.—A Leitz model polarizing microscope.

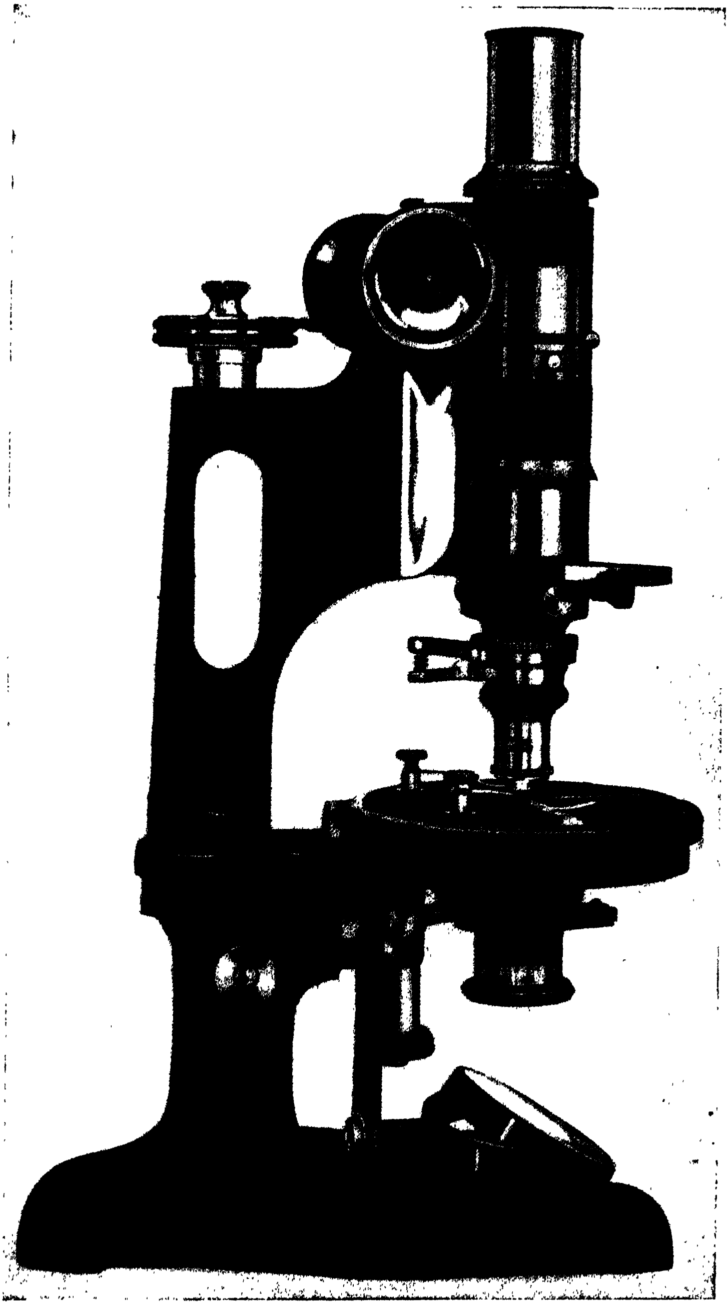

FIG. 110.—A polarizing microscope of Bausch & Lomb.

the tube. Diaphragms to cut down the field are provided, one below the stage and another below the ocular. The upper nicol may be rotated 90°, and the polarizer may be rotated through 360°. The centering screws above the objective work parallel with the cross hairs.

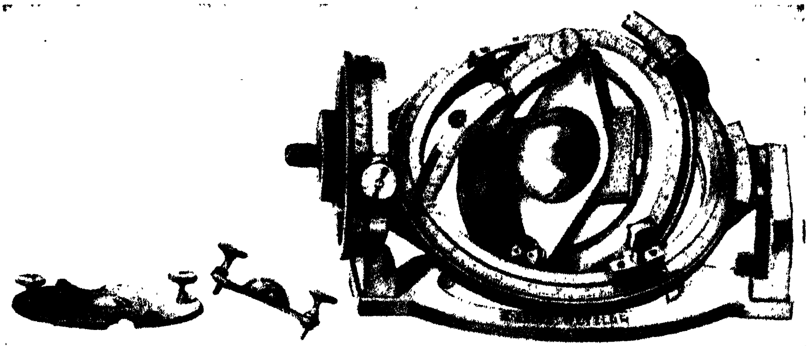

FIG. 111.—Fedoroff universal stage.

The polarizer may be lowered or even swung entirely out of the optical system. It is designed to receive the universal stage. Another Bausch & Lomb polarizing microscope has rotating nicols.

The universal stage of Fedoroff (Fig. 111), is a device which is

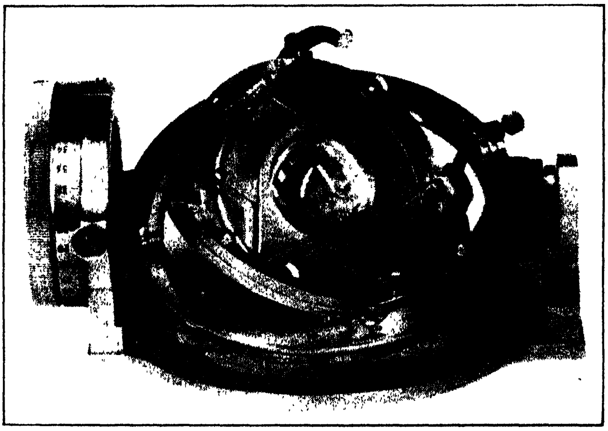

FIG. 112.—The modified universal stage. (Bausch & Lomb.)

intended to replace, or be used upon, the ordinary stage of a petrographic microscope; its chief feature is the provision for inclining or rotating the stage, not only about the axis of the microscope (as in the ordinary stage), but also about other axes which are horizontal or make variable angles with the axis of the microscope. Another essential feature of the universal stage is the presence of glass hemispheres, one above and one below the stage bearing the thin section. With these two features provided, it is possible to observe the effects of a thin section or fragment of crystal upon light passing through it not only normal to the microscopic stage, but also at any angle [4] to that plane in any direction from the normal. Furthermore, the universal stage is equipped with scales so that the angular rotation about any of its axes may be read off directly. The universal stage as modified by Emmons, (see Fig. 112), has six axes of rotation; it is described more fully in Chapter VIII.

Refractometers.—Any apparatus designed especially to measure the index of refraction of a substance is called a refractometer. If the substance is a solid which has, or can be given, a prismatic shape of suitable angle very accurate measures of the refractive index can be obtained by passing the light through the prism and obtaining the position of minimum deviation. This requires an accurate measure of the angle of minimum deviation and also of the angle of the prism. The method is not easily applied to liquids and cannot be used to measure the refractive index of solids in a finely powdered state. The refractive index is more frequently measured by the method of total reflection; for this purpose several refractometers are available; a very simple type giving only approximate results was designed by

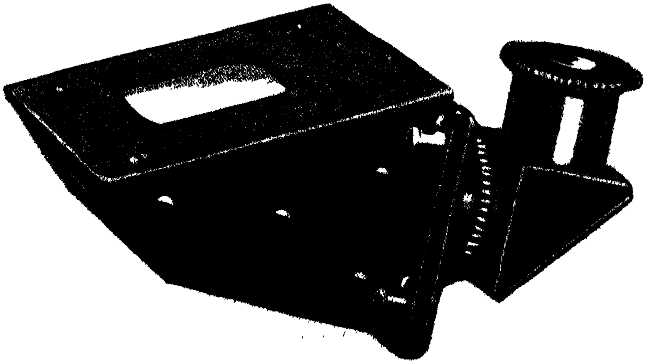

FIG. 113.—Smith's refractometer.

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[4] Theoretically the limit of this angle is 90°, but this requires that the crystal, the immersion liquids, the glass slide, the cover glass, and the glass hemisphere all have exactly the same index of refraction; practically, the ordinary limit of this angle is about 60° or 70°.

G. F. H. Smith and made by J. H. Steward of London; more accurate measures can be obtained by means of the type designed first by E. Abbé and now made with various improvements by Zeiss, Bausch & Lomb, Spencer, and others.

Smith's refractometer, shown in Fig. 113, is an apparatus devised to measure index of refraction by means of its relation to the critical angle. Any liquid is applied directly to the flat surface of a hemisphere of dense glass, having a refractive index of 1.79, and so inclined to the axis of the instrument that the center of the field corresponds to an index of 1.61. At the eyepiece of the instrument, a scale is seen within, across which falls a boundary between light and dark, which is the line limiting total reflection for the substance under examination. From the scale, the index is read at this line directly to the second place of decimals, and the intervals are such that the tenths of each can be estimated. The index of any solid may be determined just as easily and satisfactorily, provided a liquid whose index is higher than that of the solid be interposed between a polished surface of the solid and the flat surface of the hemisphere. This liquid is necessary in order to eliminate the air film which is otherwise present. Methylene iodide (with or without dissolved sulphur) is a convenient liquid for this purpose.

Total reflection refractometers equipped with Abbé prisms as made by Zeiss, Spencer, and Bausch & Lomb are shown in Figs. 114–116. The Abbé prisms are two similar, flint glass prisms of high refractive index. The refractive index of liquids (and also of solids) varies with the temperature; therefore it is important to measure the index at a temperature which can be controlled and measured. For this purpose the Abbé prisms are cemented in hollow mounts through which water of variable temperature can be circulated. A thermometer serves to give the temperature of the water passing through the prism mounts; the liquid whose index is to be measured forms a thin film between the prisms and is therefore at the same temperature as the prisms. The border line of total reflection is observed by means of a telescope, and to bring this line to the intersection of the cross hairs the Abbé prisms are rotated about an axis perpendicular to the axis of the telescope. When the index of refraction of a solid is measured only one Abbé prism is used and contact between the solid and the prism is obtained by means of some liquid. The index of refraction of the contact liquid and of the Abbé prism must be higher than that of the substance. An Abbé refractometer is less expensive and is nevertheless believed to be more accurate when it contains no Amici prisms,

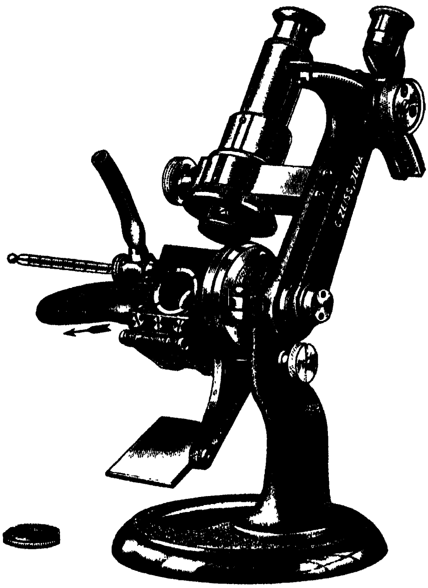

FIG. 114.—A Zeiss refractometer.

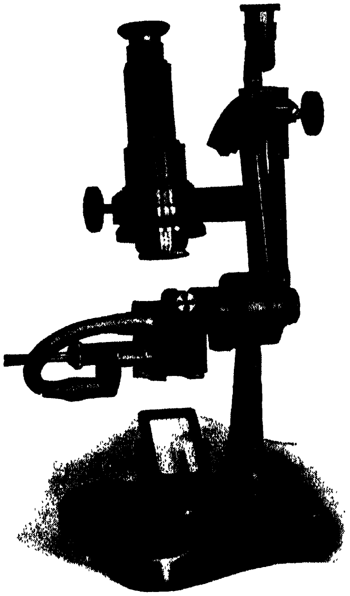

FIG. 115.—A Spencer refractometer.

which are necessary when using white light, but quite unnecessary for the measurement of refractive indices by monochromatic light.

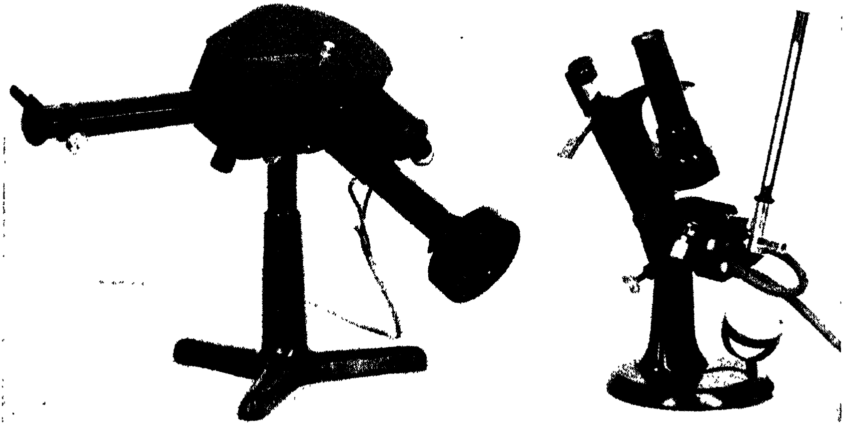

FIG. 116.—A Bausch & Lomb monochromator and refractometer.

Differences in the Abbé refractometers of different manufacturers can scarcely be noticed in the optical effects; but the instruments do differ somewhat mechanically. For most purchasers, therefore, the personal preference for a mechanical design decides the instrument to be selected. Reference is made particularly to the methods of coarse and fine adjustment that can be seen in the figures.

The chief disadvantage of total reflection refractometers as used in immersion work with solids is that, as ordinarily made, they cannot be used to measure indices greater than about 1.70. However, Spencer has recently designed and made available an instrument reading from 1.45 to 1.84; this instrument in its present form is not to be considered a substitute for the Abbé refractometer of standard range (1.30–1.71), because it employs prisms of soft, slightly yellow, glass which require very careful use. The prism surfaces should be cleaned only with fresh lens paper (to avoid scratching). Liquids of high refractive index must not be left on the prism surfaces longer than necessary because such liquids almost invariably contain iodine, which tends to combine with the lead in the high-index special glass used in the prisms, forming an opaque film on their surfaces. This apparatus is almost indispensable for measuring indices above 1.74 by the double variation method. It is shown in Fig. 115.

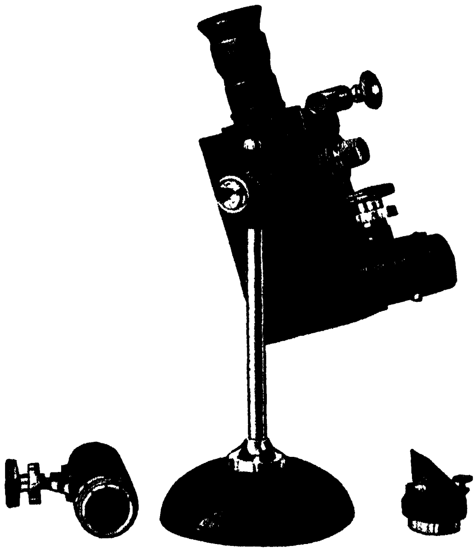

FIG. 117.—A Leitz monochromator.

Monochromators.—For the accurate measurement of optic properties of solids, monochromatic light is necessary, because these properties vary with the wave length, and ordinary daylight is constant in quality. Monochromatic yellow (red or green) light can be obtained by vaporizing sodium (lithium or thallium), for example, by placing a piece of NaCl on a Meker burner in a dark room, but a more convenient and useful source of any kind of monochromatic light consists of one or more prisms arranged to produce a spectrum before which a slit may move so as to permit the passage of light from only one narrow portion of the spectrum. Such an instrument is called a monochromator.

The Bausch & Lomb monochromator illustrated in Fig. 116 uses a constant deviation prism; the wave length may read directly. All the optical elements and moving mechanical parts are completely enclosed to eliminate dust and stray light, which will seriously impair the efficiency of the apparatus. The wave length may be read on a large drum, conveniently placed.

The Leitz monochromator shown in Fig. 117 is similar in principle, but does not provide direct reading of the wave length; it has a graduated drum which must be calibrated.

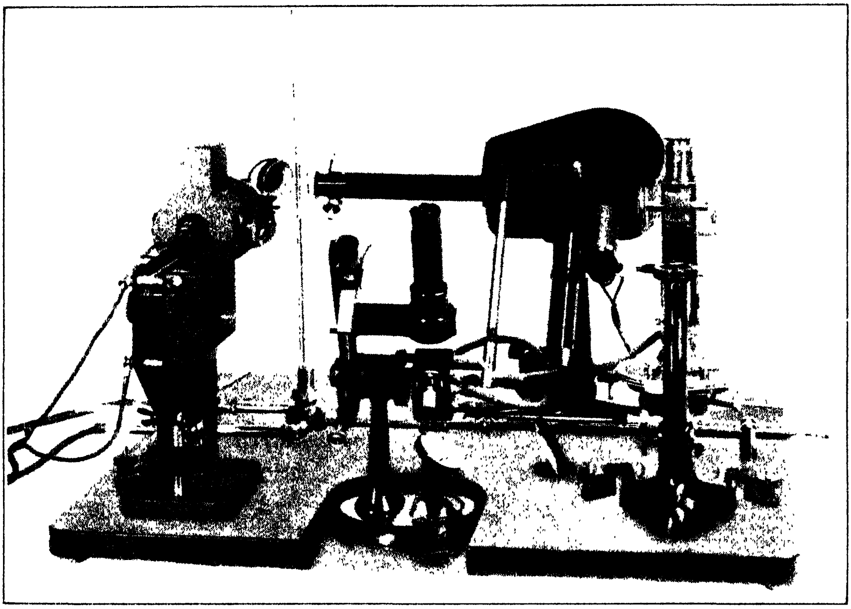

FIG. 118.—Bausch & Lomb set-up of the double variation apparatus.

Emmons' double variation apparatus.—Bausch and Lomb have assembled on a special base an arc lamp, monochromator, polarizing microscope (with space for the universal stage) and Abbé refractometer according to a design worked out by R. C. Emmons for convenient use in measuring the two or three indices of refraction of a single crystal particle under the microscope by the double variation method. This apparatus is shown in Fig. 118.

Preparation of Material for Microscopic Study.—Artificial inorganic solid substances are often obtained by precipitation from solution; such substances should be separated from the solution as the first step in preparing them for microscopic study. To make this separation complete, the substance is usually dried either by merely allowing the remaining liquid to evaporate, after decantation or filtration, or by applying more or less heat. In either case, but especially if heat is used, it is important in some cases to make sure that the process has produced no change in the substance. To avoid producing any change in the substance the drying should be accomplished slowly with no more increase in temperature than necessary.

Dry substances may be prepared for microscopic study in two different ways: they may be reduced to a fine powder by crushing (grinding is not desirable) or they may be ground to a thin slice or thin section. The first method is accomplished much more easily and quickly and is therefore preferred except when it prevents attaining some purpose of the study, such as learning the mutual relations of the constituents of a solid aggregate like brick or cement.

A dry substance which is finely powdered should be brought to approximate uniformity of size by sieving. The largest particles which pass a 240 mesh sieve are suitable for microscopic study, being about .06 millimeter in their major dimensions. The sieve should be of accurate construction, so that the openings are of known and uniform size. For most purposes of the microscopist it should also be of small size, such as the 3-in. size made by the Tyler Company of Cleveland or the Multimetal Company of New York. The purpose of sieving is twofold; namely, to eliminate both the particles which are so large they would unduly raise the cover-glass and also the particles which are so small they can not be studied satisfactorily themselves and serve merely to cloud the other particles. Such extremely fine particles are common in some precipitates, such as the ordinary precipitate of $BaSO_4$, and also in ordinary clay.

When a dry substance has been powdered and sieved it is sufficient for some purposes to put the particles on a glass slide, place a cover glass over them and immerse them in water by placing a drop at the edge of the cover glass; capillarity will draw it under the cover glass. Water has an index of refraction (1.33) which is much lower than that of nearly any solid substance; it is better for most purposes of microscopic study, and necessary for some purposes, to use a liquid whose index of refraction is nearer that of the solid. Liquids easily obtained and convenient in use include glycerine, N = 1.46; xylol, N = 1.49; cedar oil, N = 1.51; clove oil, N = 1.53; monobrombenzol, N = 1.56; bromoform, N = 1.66; and cassia oil, N = 1.606; α-monobromnaphthalene, N = 1.66; and methylene iodide, N = 1.74. For permanent mounting, Canada balsam (N = 1.54) is most convenient. By evaporating the balsam at a gentle heat until a minute drop taken out on a pin point and chilled on the thumb nail is hard rather than pasty, it is made ready for use. Or a solution of balsam in xylol may be used; the xylol gradually evaporates, leaving balsam of proper consistency. To prepare a permanent mounting, it is best to cover the center of the glass slide with a layer of balsam and scatter the fragments upon it; then add a cover glass whose lower surface has a thin coating of liquid balsam. In this way the fragments can be scattered somewhat uniformly and not crowded together on the slide.

Occasionally it is desirable to prepare thin sections of fragments. This may be done by embedding them in balsam on a cover glass which is itself cemented by balsam to a thicker glass plate. The mineral ragments should be pressed deep into the balsam. After the latter is well hardened, the surface is ground off until the fragments are reached and given a smooth polish. After thorough cleaning, the cover glass is removed by rapid heating of the glass plate and cemented in inverted position to a second glass plate previously given a thin layer of balsam. While cooling, the cover glass should be under moderate pressure so as to push the polished solid surfaces down upon the glass plate. After grinding away the cover glass, the fragments are given second surfaces parallel to the first ones, and are carefully ground until sufficiently thin. Then they are cleaned and made ready for study by simply cementing a cover glass over them.

CHAPTER III

OPTIC PROPERTIES OF ISOTROPIC SUBSTANCES

Light is a form of energy which may be considered to consist of a wave motion in the ether. Waves of light are very short; the wave length of the yellow light of sodium is 0.000023 of an inch or 0.000589 of a millimeter. The period of vibration of light is extremely short, about 510 million million vibrations of sodium light occurring in one second. Light travels with great velocity, about 186,000 miles per second. The velocity of light of all wave lengths is the same in a vacuum; therefore, the period of vibration is exactly proportional to the wave length. Ether waves of different periods of vibration (and of different wave lengths) give rise to different colors of light. The wave length of violet light, at one end of the spectrum, is about 0.000380 mm., while that of red, near the other end, is about 0.000760 mm. The velocity of light is less in most substances than in a vacuum, and varies with the substance and also with the wave length; therefore, in any medium, whether gaseous, liquid, or solid, violet light has one velocity and red light another, which is greater.

Wave-front.—If wave motion of light be produced at a point in a vacuum, it will be transmitted outward from the point in all directions at the same velocity. Therefore, at any instant, all points in the same phase will be equally distant from the point of origin. The focus of all these points is called the wave-front, and in this instance it is a spherical surface. If the wave motion originated in a plane instead of a point, it would be transmitted in spherical waves from every point of the plane; and the plane tangent of all these waves on each side of the plane of origin would be the wave-front. If the wave motion were transmitted from a point at velocities varying gradually with the direction, the wave-front would be a warped surface of some kind.

The line along which the wave motion travels from the point of origin to any point on the wave-front is called a ray. In a vacuum the light ray from the point of origin to any point on the wave-front is perpendicular to the tangent plane at that point.

Isotropic substances (like the ether of a vacuum) transmit light with equal velocity in all directions. They include all gases, most liquids, and all glasses and isometric crystals, when not under strain.

Anisotropic substances transmit light with unequal velocities in different directions; they include all crystals, except those of the isometric system which are unstrained. Glass under strain is also anisotropic. In non-isometric crystals the velocity varies gradually with the direction in such a way that most sections of the wave-front are elliptical. In Fig. 118*a* it may be seen that the light ray from the point of origin to any point on the wave-front is not perpendicular to the tangent plane at that point except when the ray coincides with the major or minor axis of the ellipse. The line *VW* perpendicular to the tangent plane is called the wave-normal. When the wave-front is an elliptical surface, as in Fig. 118*a*, the wave-normal does not coincide with the light ray except in the directions of the principal axes of the ellipse. In isometric crystals the wave-front is spherical; in all other crystals it is ellipsoidal.

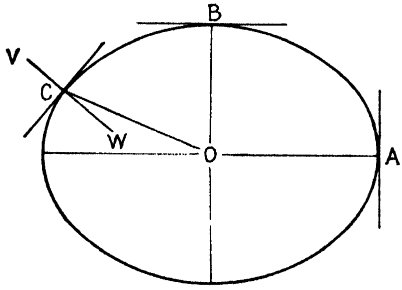

FIG. 118a.—Wave-front in an anisotropic substance.

Refraction.—When light strikes a boundary between two isotropic substances, that portion which penetrates the second medium is, in general, turned somewhat from its previous direction. This is called refraction, and the property (of the substance) to which it is due is called refringence.

For monochromatic light and isotropic substances, the velocity in one medium divided by the velocity in another medium is constant; it is commonly denoted by N, then:

$$N = \frac{v}{v'} = \frac{\sin i}{\sin r}$$

that is, the constant N is equal to the ratio between the velocities of light in the two substances and this is the same as the ratio between the sine of the angle of incidence and the sine of the angle of refraction. Also, the incident and refracted rays lie in a common plane with the normal to the surface (assuming both substances to be isotropic).

The velocity of light is less, the denser the medium—therefore, when light passes from a rarer to a denser medium, the ratio $\frac{v}{v'} = \frac{\sin i}{\sin r}$ is greater than unity, the angle of refraction is less than the angle of incidence, and the refracted ray is bent toward the perpendicular to the surface. Also, when light passes from a denser to a rarer medium, the ratio $\frac{v}{v'} = \frac{\sin i}{\sin r}$ is less than unity, the angle of refraction is greater than the angle of incidence, and the refracted ray is bent away from the perpendicular to the surface.

The constant N is called the **index of refraction** of the second medium as compared with the first. The medium chosen as a standard and assigned a refractive index of unity is the ether of a vacuum. Air has an index (1.000294) so near unity that it is commonly used as a more convenient standard. After measurement of the index of a substance in any medium, as air, its index in a vacuum may be computed. It is equal to the index measured multiplied by the index (measured in a vacuum) of the medium used.

The index of refraction of any substance varies for different colors of light and increases as the wave length decreases; therefore, the index for violet light is greater than for red, while the index for the yellow light of sodium (Na) is commonly used as an approximate mean value for all parts of white light.

The refringence of a substance is its power to produce refraction of light; it is measured by its index of refraction.

Microscopic methods for direct measurement of the index of refraction in thin sections are not as accurate as others; however, microscopic methods for comparing the indices of refraction of two substances in contact are of a high order of accuracy, and they may be used indirectly to determine indices by the use of normal illumination or oblique illumination.

Normal illumination.[1]—When the contact between two substances of unequal refringence is observed microscopically, a narrow band of light, sometimes called the " Becke line," may be seen under favorable conditions. Such a contact is usually inclined more or less to the object glass, so that each substance is thinner on the edge than away from it

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[1] The illumination best adapted for this method is "normal" in both senses; that is, it is normal or usual in contrast with the special illumination of the next method, and it is normal or at right angles to the plate (on the average) unlike the case of oblique illumination.

(toward its center); therefore, each edge acts like that of an imperfect lens to refract and concentrate the light on one side or the other of the boundary, depending chiefly upon the relative values of the indices of refraction of the two substances.

With powdered substances immersed in liquids nearly all the fragments are thinner on the edge than in the center and therefore act as imperfect lenses to refract the light, provided they differ in index from the liquid. If the fragment has a higher index than the liquid it tends to bring parallel light to a focus above the fragment; consequently, a slight *raising* of the objective from good focus on the particle causes brightness within the area of the fragment. If the substance has a lower index than the liquid it produces a virtual focus of previously parallel light below the particle, consequently, a slight *lowering* of the objective from good focus on the fragment causes brightness within the particle. In both cases the reverse motion of the objective causes a bright line of light outside the fragment while the particle itself becomes darker than the field in general. Therefore, the rule is that the bright line moves toward the substance of higher index when the focus is raised and toward the substance of lower index when it is lowered.

In using this method it is necessary to employ a medium, or preferably, a high-power objective and focus accurately upon the line of contact; then lower the condenser enough to notably darken the field of view (if the condenser cannot be lowered enough the mirror may be shifted or a diaphragm partly closed) and a very fine line of white light, clearer and brighter than the mineral on either side, may be seen very close to the line of contact. This bright line is the " Becke line"; it moves toward the mineral of higher index when the focus is very slightly raised. The plane of contact should be normal or nearly normal to the plane of the section for the best results.

Oblique illumination.—By the use of oblique illumination the same phenomenon may be made more distinct, so that differences of index as small as .001 may be detected promptly under favorable conditions. It is only necessary to shade part of the field so that the boundary being studied is in the half-shadow portion of the field of view. The shading or darkening of part of the field may be accomplished by tilting the mirror, or by intercepting part of the light from the mirror in any way—most conveniently by interposing the finger. In case the boundary is inclined it causes refraction much as the edge of a lens would do, as it does with normal illumination, and this effect is made more evident by using oblique illumination. In case the boundary is normal to the object glass the effect is easily understood from Fig. 119 in which *A* is any mineral surrounded by a second mineral (or liquid), *B* and *B'*. An inclined beam of light passing from *B'* into *A* is made narrower or condensed since each ray is refracted away from the perpendicular to the contact plane, while a similar beam of light passing from *A* into *B* is widened or dispersed by refraction toward the perpendicular. If the mineral is above the focus of the condenser when the edge appears bright (as in passing from *B'* to *A*) the mineral of higher refringence is on the side whence the light comes, and when the edge appears dark (as in passing from *A* to *B*) the mineral of lower refringence is on the side whence the light comes.

If the mineral is below the focus of the condenser the effects are reversed. The reversal of the effect is due to the fact that the change of condition is equivalent to inserting the shade above or below the focus of the condenser, and therefore the direction of inclination of the light is reversed. To determine whether the crystal is above or below the focus of the condenser it is only necessary to move the condensing lens up or down until the edge of the finger or object shading the mirror is in good focus; when the condenser is raised from this position the mineral is below the focus; when it is lowered from this position the mineral is above the focus.

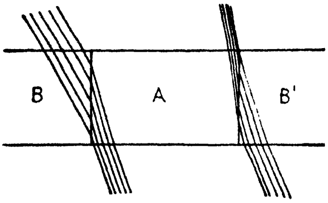

FIG. 119.—Oblique illumination.

In using this method it may be noted that the direction of inclination of the beam of light is reversed by the substage lenses and again reversed by the objective; hence the phenomena may be read as if no reversal took place.

With Leitz microscopes the ordinary method of cutting off the light with the finger to secure inclined illumination gives poor results; good results can be obtained by using the brass frame of a gypsum or mica plate (inserted in its usual place) to produce inclined illumination. Even better results can be obtained by employing a special shader, recently devised for use immediately below the condenser. In this case the effects are reversed as compared with using the finger with other microscopes, because the condenser must be removed and therefore the mineral is below the focus of the weak condensing lens which remains.

As compared with crystals or other solids, liquids in general have much greater dispersion, that is, they have much greater differences in indices for different parts of the spectrum. Therefore, if a crystal has exactly the same index of refraction as a certain liquid for yellow light, it will have greater refringence than the liquid for red light and less than the latter for blue light. Under these conditions if a fragment of the crystal is observed with inclined illumination in white light one edge of the fragment is colored by blue light and the opposite edge by red light. The blue edge will be on that side of the crystal away from the shadow (condenser being lowered), which is the side that is brightly illumined when the crystal is immersed in a liquid of higher refringence, or, without change of liquid, when monochromatic blue light is used instead of white light. Accordingly, the appearance of pale red and blue edges on opposite sides of a crystal is evidence that the fragment has a refringence equal to that of the liquid for some intermediate color. For some of the immersion liquids—notably cinnamon oil—the dispersion is very great and strongly colored borders are present even if the index for sodium light of the grain and the liquid differ in the second decimal place.

Immersion Method.—Schroeder van der Kolk brought into prominence a method to determine the refringence of minerals in fragments or grains. It consists essentially in immersing the fragment in a liquid of the same refringence, as determined by the method of normal or inclined illumination, and then measuring the index of refraction of the liquid. A liquid of the same refringence may be obtained by reducing the index by dilution or raising the index by evaporation, or it may be obtained approximately by preparing beforehand a set of liquids whose indices differ by only a small amount, for example, by 0.01. Changes of temperature or of concentration through evaporation modify the refringence of liquids and should be avoided during use. The liquids recommended for this use by Larsen [1] are given on page 62. These liquids are selected partly because of relatively low dispersion. They may be kept conveniently in small dropping bottles with ground-glass dropper and cap, thus providing two ground joints to prevent evaporation. All the liquids, except as noted, will form suitable mixtures in any proportions with those next above and below them in the table. The index of refraction decreases with increase of temperature at the rate given for (1° C.) in the column headed dN/dT.

A set of prepared liquids with a regular difference of index of 0.005 may be obtained from the Eastman Kodak Company of Rochester,

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[1] *U. S. Geol. Survey Bull.* 679, 1921, p. 15.

IMMERSION MEDIA AND THEIR PROPERTIES

Substance	N at 20° C.	$\frac{dN}{dT}$	Dispersion	Remarks
Water	1.333	Slight	....	Dissolves many minerals of low index.
Acetone	1.357	....	Slight	
Ethyl alcohol	1.362	0.00040	Slight	Dissolves many minerals of low index.
Ethyl butyrate	1.381	....	Slight	
Methyl butyrate	1.386	....	Slight	
Ethyl valerate	1.393	....	Slight	
Amyl alcohol*	1.409	.00042	Slight	Dissolves many minerals of low index.
Kerosene	1.448	.00035	Slight	
Petroleum oil:†				
Russian alboline	1.470	.00040	Slight	
American alboline	1.477	.00040	Slight	
Valvolene‡	1.502	.00040	Slight	Will not mix with clove oil.
Clove oil	1.531	.00050	Moderate	Mixes with petroleum oil with difficulty; may be mixed readily with rapeseed oil, index of which is 1.471.
Cinnamon oil§	1.585–1.600	.0003	Strong	
Cinnamic aldehyde	1.615	.0003	Strong	
α-Monobromnaphthalene‖	1.658	.00048	Moderate	
Methylene iodide	1.74±	.00070	Rather strong	Expensive, discolors on exposure to light, but a bit of Cu or Sn will prevent this change.
Methylene iodide saturated with sulphur	1.778	....	Rather strong	
Methylene iodide, sulphur and iodides¶	1.868	....	Rather strong	
Piperine and iodides	1.68–2.10			
Sulphur and selenium	2.0–2.7	....	Very strong	
Selenium and arsenic selenide	2.72–3.17	....	Very strong	

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* Ordinary fusel oil may be used instead; it forms a milky emulsion with kerosene, which settles on standing, so that the clear liquid can be decanted off.

† Any of the medicinal oils may be used, such as Nujol.

‡ Any clean lubricating oil, such as used in automobiles, may be used.

§ Less expensive than cinnamic aldehyde, but the index of commercial oil is not definite.

‖ Mixtures of α-monobromnaphthalene with clove oil give liquids with less dispersion than those with cinnamon oil.

¶ To 100 grams of methylene iodide add 35 grams iodoform, 10 grams sulphur, 31 grams tin iodide (SnI_4), 16 grams arsenic iodide (AsI_3), and 8 grams antimony iodide (SbI_3), warm to hasten solution, allow to stand, and filter off undissolved solids. See H. E. Merwin: *Jour. Wash. Acad. Sci.*, III, 1913, p. 35.

N. Y. This set begins preferably at about 1.440 and continues to 1.740; the liquids above 1.740 change in index so rapidly that only the sulphur saturated methylene iodide (1.78) is desirable as permanent equipment. Such a set in bottles with ground-glass stopper elongated as a glass rod below and having a flat top is shown conveniently arranged in a substantial tray in Fig. 120 on page 64.

A set of liquids convenient for approximate determinations, because preliminary measures of the indices of the liquids are unnecessary, is given below. Most of these are easily obtained. But for precise work the indices must be measured as different lots of the same material in some cases give results varying as much as 0.04:

Index	Liquid	Index	Liquid
1.33	Water	1.56	Monobrombenzene
1.36	Ethyl alcohol	1.59	Bromoform
1.44	Chloroform	1.60	Cassia oil
1.47	Glycerine	1.62	Monoiodobenzol
1.48	Castor oil	1.64	α-Monochlornaphthalene
1.49	Xylol	1.66	α-Monobromnaphthalene
1.50	Benzene	1.70	Cadmium borotungstate
1.51	Cedar oil	1.74	Methylene iodide†
1.53	Clove oil, or monochlorbenzol	1.78	Methylene iodide saturated with sulphur
1.54	Fennel oil		
1.55	Nitrobenzene,* bitter almond oil, or anise oil		

* Alters when exposed to light.

† The iodine which separates on exposure to light may be removed with copper.

Immersion methods can be made much more accurate and useful by taking advantage of the variation of the index of refraction of liquids with variation of temperature or with variation of both temperature and wave-length, as described later.

Index-variation methods with immersion liquids are designed primarily to accomplish the accurate measurement of the index (or indices) of refraction of any solid substance. They have several very important advantages over ordinary immersion methods of estimating the index of refraction, namely:

1. Immersion methods give only a comparison of indices, while the index-variation methods give a direct measure of the index of refraction.

2. In order to learn the value of the index of refraction of a solid by the immersion method it must be immersed successively in several

different liquids, while the value can be learned with the index-variation method by immersion in one liquid. When a large amount of a pure substance is available, this is not an important difference, but in the frequent case of a sample containing several substances, it is quite important, since it is difficult, if not impossible, to transfer a particle (invisible without the microscope) from one liquid to another, and, even if the transfer is accomplished, it is very likely to introduce some of the first liquid into the second, thus changing its index. Index-variation methods are far superior to any other method in the study of soils and other powdered mineral aggregates, whether natural or artificial.

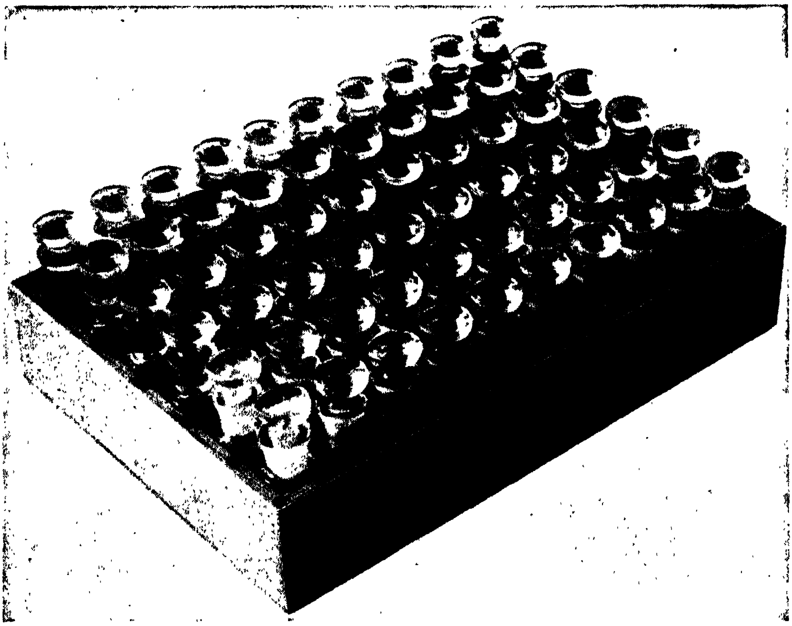

FIG. 120.—Set of index-of-refraction liquids.

3. Immersion methods give the value of the index of refraction with an accuracy of about ±.003 under favorable conditions, while the index-variation methods reach an accuracy of at least ±.001 under similarly favorable conditions. This increase in accuracy is extremely important because it permits correspondingly accurate calculations of the birefringence, the optic sign and the optic angle, and thus makes possible the precise determination of the substance in many cases left doubtful by immersion methods.

4. Immersion methods give information regarding the index of

refraction for one vibration direction in the mineral; they are often not sufficiently accurate to determine whether the index is the same or slightly different for different vibration directions; on the other hand, the index-variation methods measure the index directly and therefore permit the recognition of differences in the index in different directions even when these are less than .001.

5. Immersion methods give information regarding the index of refraction in daylight or sodium light; they are not sufficiently accurate to give data regarding the dispersion; on the other hand, the double variation method measures the index of refraction in sodium light and also the index for other wave lengths, and therefore it measures the dispersion, thus furnishing an additional means of determining the substance.

There are two types of index-variation methods which deserve attention; one kind uses only one means of varying the refractive index and may be called the single variation method; the other kind uses two means of varying the refractive index and may be called the double variation method.

The single variation method (also called the dispersion method) as proposed by Merwin[3] and developed by Tsuboi,[4] depends upon variation in wave length (or color) to vary the index of the liquid. This method is far superior in accuracy to the ordinary immersion methods, but requires equipment which is nearly as expensive as that required for the double variation method and is not as convenient as the latter. It requires the use of special equipment consisting of a dark room, a monochromator and a refractometer. The technique of measuring indices of refraction by this method is the same as that involved in using the double variation method with the single exception that all measures are made at room temperature and therefore many more liquids are required than are needed for the double variation method.

The single variation method of Emmons[5] depends upon variations of temperature to vary the index of the liquid. This method is as accurate as Merwin's method, if carried out with a dark room, sodium light, a refractometer and a device for controlling and varying the temperature. Even without the refractometer accurate results can be obtained if suitable liquids of known index and known thermal variation of index are available.

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[3] *Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1970.

[4] *Jour. Geol. Soc. Tokyo*, XXXII, 1925, No. 377; *Mineral Mag.*, XX, 1925, p. 108.

[5] *Amer. Mineral*, XIII, 1928, p. 504.

The single variation method of Emmons requires the use of a special cell shown in Fig. 121 designed so as to make it possible to vary the temperature of the immersion liquid through a suitable range, such as 10° to 50° C. The cell is used on the stage of an ordinary polarizing microscope; water of variable temperature passes through it between parallel glass windows; the upper glass window is thin to reduce thermal insulation; on its upper surface the crystal grain or powder is mounted in an immersion liquid and protected by a cover glass in the usual way. The temperature is measured by means of two ordinary thermometers, one giving the temperature of the water before it enters the cell and the other giving its temperature after it leaves the cell (or, after it leaves the refractometer, if one is used). In practice it is safe to assume that the immersion liquid has the same temperature as the water when the readings of the two thermometers differ by no more than one degree.

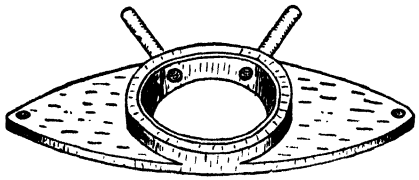

Fig. 121.—Emmons' temperature cell for variation methods.

The theory of the single variation method of measuring index of refraction is very simple, depending merely on the two facts that the index of refraction of liquids decreases as the temperature rises, while that of solids, though decreasing slightly, is so nearly constant that the temperature range employed causes changes, in general, only in the fourth or fifth decimal place. Therefore, by using a suitable liquid and varying its temperature the index of the liquid can be made to equal exactly that of the mineral. When this is accomplished the " Becke line " disappears and the particle becomes nearly invisible. Then the index of the same liquid can be read on a refractometer which is connected with the same water circulation and is therefore at the same temperature. If no refractometer is available it is necessary to assume that the index of the liquid is exactly the same as it was when measured at some previous time, perhaps before its purchase. In order to make this as probable as possible it is important to use only liquids which are pure compounds rather than solutions or mixtures because then there is no variation in index with varying concentration during evaporation. It is also important to use liquids of high thermal variation of index, and to have a series of liquids representing all indices of refraction from about 1.40 to the highest available (about 1.74), with moderate overlaps. The set of liquids recommended by Emmons is given in the following table, which also includes data as to their index of refraction and thermal variation of index. The purity of these liquids is extremely important, as small amounts of impurities destroy their value for index work.

Single Variation Liquids	N_D at 25° C.	dN/dT
1. Methylene iodide	1.737	0.00068
2. Methylene iodide + iodobenzene	1.715	.00065
3. α-Iodonaphthalene	1.699	.00047
4. α-Iodonaphthalene + α-bromnaphthalene	1.675	.00047
5. Orthobromiodobenzene	1.661	.00048
6. Phenylisothiocyanate	1.647	.00056
7. *s*-Tetrabromoethane	1.634	.00053
8. Iodobenzene	1.616	.00057
9. Bromoform*	1.594	.00060
10. Aniline	1.583	.00052
11. Orthotoluidine	1.569	.00051
12. Nitrobenzene	1.549	.00048
13. Ethylene bromide	1.535	.00056
14. Propylene bromide	1.516	.00054
15. Pentachlorethane	1.501	.00048
16. Methyl furoate	1.485	.00045
17. Methyl thiocyanate	1.466	.00054
18. Isoamylsulphide	1.451	.00045
19. Ethyl dichloroacetate	1.434	.00047
20. Ethyl monochloroacetate	1.419	.00047

* Bromoform will be replaced by a liquid of less volatility when possible, because when used hot it is necessary to replenish the supply often.

The double variation method[6] makes use of two methods to vary the index of the liquid, namely, change of temperature and change of wave length (color) of the light employed. The index of refraction of liquids increases as the wave length of the light decreases, and this variation (known as dispersion) is greater (in general) for liquids than it is for solids. Also, as already noted, the index of refraction of liquids decreases as the temperature increases, and this thermal variation of index is considerable in many liquids and negligible (affecting only the fourth or fifth decimal place) in crystals. Therefore, by using both these methods of varying the index of liquids, it is possible, not only to reduce the number of liquids which must be employed, but also to make the index of the liquid exactly equal to that of the solid at several different wave lengths (and temperatures) and thus determine the standard index in sodium light and also in all other kinds of light in many cases with a single immersion liquid; knowing the index throughout the spectrum the dispersion is easily derived. Theoretically this method can be used with pure liquids of known thermal and chromatic variation of index and no additional apparatus except the special cell described in connection with the single variation method and a burner to give " monochromatic " red light with lithium, yellow light with sodium, and green light with thallium salts in a dark room. However, it is much better to use a monochromator and a refractometer, so as to be able to measure the index of refraction of the same liquid in which the substance is immersed, employing the same temperature and the same wave length of light as that used while observing microscopically that the index of the liquid is equal to that of the solid.

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[6] R. C. Emmons: *Amer. Mineral*, XI, 1926, p. 115; XIII, 1928, p. 504; XIV, 1929, p. 414, 441, 482.

For the double variation method of measuring index of refraction, liquids should be pure compounds having high chromatic and high thermal variation of index, and they should be selected so as to include the greatest possible range in index of refraction (from 1.40 upwards) with no interruptions and with considerable overlaps. It is one of the advantages of this method that it requires only 13 liquids to cover the same range as the set of 60 liquids used for ordinary immer-

Double Variation Liquids	N_C at 50° C.	N_D at 25° C.	N_D at 50° C.	N_F at 50° C.	dN/dT
1. Methylene iodide	1.711	1.737	1.721	1.747	0.00068
2. α-Iodonaphthalene	1.678	1.699	1.687	1.714	.00047
3. α-Iodonaphthalene + α-bromnaphthalene	1.654	1.675	1.663	1.687	.00047
3a. Orthobromoiodobenzene	1.640	1.660	1.647	1.665	.00052
4. Phenylisothiocyanate	1.624	1.647	1.633	1.659	.00056
4a. s-Tetrabromoethane	1.611	1.634	1.619	1.635	.00057
5. Iodobenzene	1.596	1.616	1.602	1.620	.00057
6. Bromoform	1.574	1.594	1.579	1.592	.00060
7. Orthotoluidine	1.550	1.569	1.557	1.572	.00051
8. Orthonitrotoluene	1.525	1.544	1.531	1.548	.00049
8a. Ethylene bromide	1.519	1.536	1.522	1.535	.00054
9. Propylene bromide	1.499	1.516	1.502	1.511	.00054
9a. Pentachlorethane	1.483	1.502	1.489	1.499	.00048
10. Methyl furoate	1.469	1.485	1.473	1.485	.00045
11. Methyl thiocyanate	1.449	1.466	1.452	1.459	.00054
12. Trimethylene chloride	1.431	1.446	1.434	1.439	.00049
13. Ethyl monochloroacetate	1.405	1.419	1.407	1.412	.00047

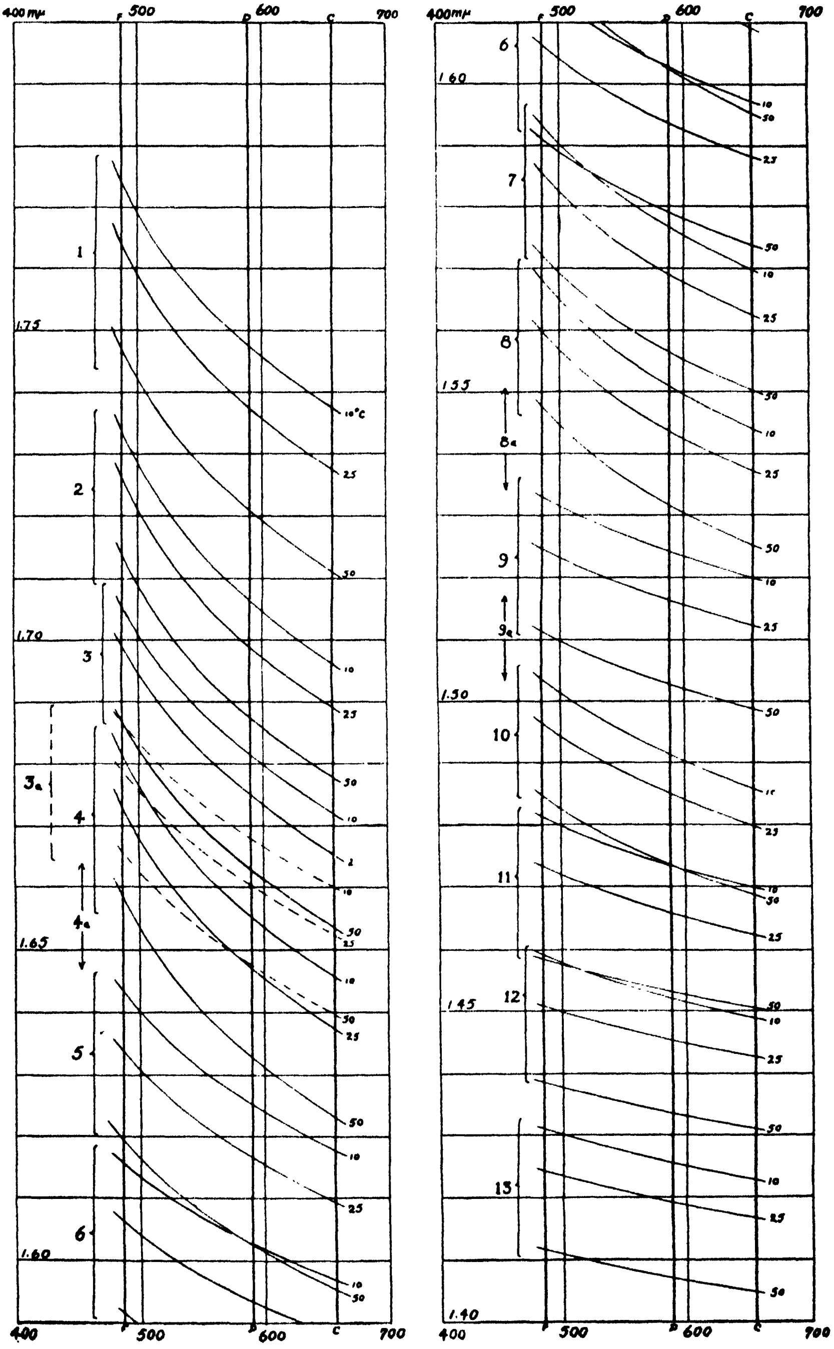

FIG. 122.—Dispersion curves for double variation liquids.

sion work with daylight. The liquids recommended by Emmons are given on page 68, with data regarding their index in sodium light, their dispersion and their thermal variation of index. These data are summarized in convenient form in Fig. 122 on page 69.

DIRECTIONS FOR LABORATORY WORK

Determine the relative refringence of two substances in contact by two different methods. In using the method of normal illumination it is necessary to focus sharply with a high-power objective on the contact to be studied, and then lower the condenser, or partly close the substage diaphragm, or both, producing poor illumination of the field. This will render visible a fine bright line, close to the contact. When the focus is slightly raised the bright line moves toward the mineral or substance of higher index. The contact between any two substances in any thin section may be studied in this way, and differences of index as small as 0.002 may be detected. Still smaller differences may be distinguished by the method of oblique illumination. For this method, low power objectives are used; the condenser is slightly lowered, and one-half of the field is darkened by interposing the finger or other object above the mirror so as to cut off one-half of the beam of light. If the edge appears darkened, the substance of lower refringence is on the side whence the light comes; if it appears brightened the reverse is true.

By immersing minute fragments in liquid, determine, by both of the preceding methods, whether quartz has a higher or lower index than (1) glycerine, (2) cinnamon oil or cassia oil.

Single variation method. With equipment for the single variation method, first make a preliminary examination of the unknown material in powder form by the ordinary immersion method in daylight in order to learn the approximate refractive index, so as to be able to choose the proper immersion liquid for dispersion work. This step is quite unnecessary if the purpose in mind is to identify all the substances of an aggregate like a sample of soil; in that case a sample of the aggregate should be studied in each one of the liquids of the single variation set beginning with the one of the lowest index, until a liquid is reached which has a higher index than any substance in the aggregate. In case the aggregate contains one or more substances having indices higher than 1.75±, these substances must be studied by other methods, such as immersion in piperine and iodides or in sulphur-selenium melts. When a grain is found not widely different in index from the index of the liquid at one of its extinction positions, the temperature of the liquid is raised or lowered as may be necessary to make the index of the liquid exactly equal to that of the substance. Of course, the temperature must be raised by circulating warm water through the cell, if the index of the liquid is higher than that of the substance; otherwise, the temperature must be lowered. When the index of the liquid exactly matches that of the grain, the "Becke line" disappears and the grain becomes nearly invisible. Such a result can not be obtained with white light because of the difference in dispersion between the liquid and the solid. Monochromatic light is needed; it is easily obtained by vaporizing NaCl in a Bunsen burner flame in a dark room. Then the index of the same liquid should be read on a refractometer using the same water circulation and therefore at the same temperature. If no refractometer is available, the index of the liquid for the temperature in question must be taken from tables, such as given on page 67. Next the grain should be rotated 90° to its second extinction position and the temperature changed again until the index of the liquid again matches that of the solid, if that is possible. If that is not possible, it should be noted that the second index of the mineral is higher than the highest index attainable with the given liquid or lower than the lowest attainable. The next step is to roll the grain over to another position, unless other grains are available which are known to be the same substance. Then the index of refraction in both positions of extinction should be measured in the same way on the grain in the new position or on another grain of the same substance. Finally, the grain should be rolled over to a third position approximately 90° from both the preceding ones and the two indices of refraction measured once more. If several grains of the same substance are available, it is usually sufficient to read the one index of refraction of a grain showing minimum birefringence and both indices of refraction of a grain showing maximum birefringence. The first index measured will be very near N_o or N_m and the two others will be very near N_o and N_e, or N_g and N_p. After completing the task with a given immersion liquid, another sample of the aggregate should be studied in another immersion liquid in the same way. The data thus assembled should permit the identification of most, if not all, of the substances in the aggregate by the use of tables for the determination of substances by means of their optic properties.

Double variation method.—With equipment for the double variation method a smaller number of liquids suffices to cover the same range of refractive indices (1.40–1.75±). With this method one thermometer should give the temperature of the circulating water before it enters the special cell and the other after it leaves the refractometer. The same immersion liquid is put on the refractometer that is used to mount the sample. A monochromator is an important part of the equipment for this method; if necessary, monochromatic light from lithium, sodium and thallium salts can be used as a substitute. The ordinary refractometer reads directly in sodium light; a correction curve must be obtained from the instrument maker (or made) in order to convert readings at other wave lengths to their true values. Before using this method the same preliminary examination should be made as for the single variation method. Then the powdered sample should be mounted in a suitable immersion liquid on the thin upper glass of the temperature cell and protected with a cover glass. When the index of the liquid has been brought to equality with that of a grain at an extinction position the index of the same liquid should be read at the given temperature and with the same light on the refractometer. If this is accomplished first at a temperature of about 50° C. and with a wave length in green, a lower temperature, such as 35° C. should be used next. At this temperature the index of the liquid will be higher than before while that of the solid will be practically unchanged. By gradually increasing the wave length of the light, the index of the liquid will again become equal to that of the solid, perhaps in yellow. This result is due to the fact that increase of wave length lowers the index of the liquid faster than it does the index of the solid. By repeating this process for a third temperature and a third wave length, perhaps in red, three points can be found which will locate a curve representing the index of refraction of the solid for all wave lengths. From such a curve, illustrated in

Fig. 123, two optic properties of the solid substance may be read easily and accurately, namely, the index of refraction for sodium light (used because sodium light is obtained so easily and because this index is approximately equal to the mean value for white light) and the dispersion, or difference in index of refraction of the substance for different wave lengths. The standard difference used in expressing the dispersion is that between the index for thallium light and for lithium light, or, preferably, that for the *F* line in blue and the *C* line in red; this may be expressed briefly as $N_F - N_C$.

As a test of the double variation method, powder a fragment of quartz and immerse it in liquid number 8 (orthonitrotoluene) on the upper surface of Emmons' temperature cell. Find a grain showing maximum interference colors. Using a monochromator and a refractometer in a dark room with the cell and refractometer

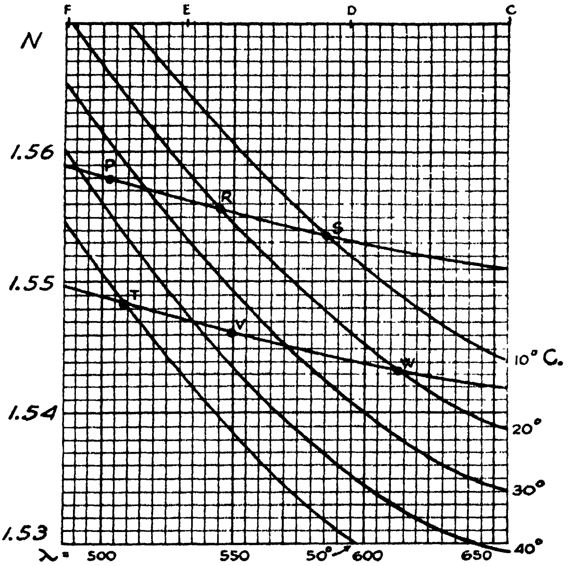

FIG. 123.—Determination of refractive indices and dispersion of quartz by the double variation method.

at 10° C. the higher index of the grain will equal that of the liquid at wave length 587 and the refractometer reading will give as the index: 1.5537, thus locating the point *S*, on Fig. 122; the wave length can not be increased sufficiently (within the range *F–C*) to make the index of the liquid equal to that of the grain in the other extinction position. Then, at 20° C., the points *R* and *W* can be located in the same way; at 35° C., the points *P* and *V* can be located; finally, at 50° C. the point *T* can be located. Next, trying a grain showing the lowest interference color, the single index of refraction will be found for various temperatures exactly along the line *TVW*. Therefore the mineral is uniaxial and positive. It is easy to read from the diagram that $N_o = 1.542$ *C*, 1.544 *D*, 1.550 *F*, $N_e = 1.551$ *C*, 1.553 *D*, 1.559 *F*; therefore $N_e - N_o = .009$ and $N_F - N_C = .008$. These are the correct data for quartz.

CHAPTER IV

OPTIC PROPERTIES OF UNIAXIAL CRYSTALS

CERTAIN crystals, when properly oriented, resolve the complex vibrations of white light into vibrations acting in two planes, at right angles to one another. Such light is said to be *plane polarized.* Light whose vibrations take place in a circle or an ellipse is called *circularly* or *elliptically polarized* light. Such light is produced by certain sections of a few crystals of inferior grade of symmetry.

Polarization.—The process of resolving the extremely complex vibrations of ordinary light into vibrations taking place in definite directions or in definite planes is called polarization. Light may be polarized in several different ways:

Polarization by isotropic substances.—When ordinary light, which is vibrating in all directions normal to the direction of propagation, strikes obliquely the surface of an isotropic medium, it is divided into a refracted and a reflected ray, both of which are partly polarized. It seems to be true that those vibrations of the incident light which are most nearly perpendicular to the surface of the medium penetrate it most easily, while those vibrations which are most nearly parallel to the same surface are reflected most abundantly. Also, vibrations of an intermediate position seem to be more or less completely resolved into two components, one vibrating parallel to the surface and being reflected, the other vibrating at right angles to the first and being refracted. The amount of the incident light which is polarized in this way varies with the angle of incidence; it should be none at all for absolutely normal incidence, and it increases to a maximum at that angle of incidence at which the reflected and refracted rays are at right angles. Therefore, at that angle of incidence which gives maximum polarization, $N = \tan i$.

In Fig. 124, the incident ray AO is vibrating in all directions normal to the ray; upon striking the surface of the new medium BC at the angle which gives maximum polarization, it is divided into a reflected ray OD, vibrating parallel to the surface and normal to the ray, and a refracted ray *OE*, vibrating at right angles to the former and normal to the ray.

Polarization by anisotropic substances.—The single plane surface of an isotropic substance produces polarization, which is commonly partial, but the innumerable regular layers of atoms of anisotropic substances produce complete polarization both in the reflected and refracted rays, except in a few special cases. In most cases, crystals produce plane polarized light, the position of the planes of vibration having a definite relation to the atomic structure of the substance. In some cases crystals produce circularly polarized or elliptically polarized light. Anistropic crystals not only polarize the reflected and refracted rays, but they also generally divide refracted light into two parts traveling at different rates and along different paths, and polarized in planes at right angles to each other. This division of the refracted light into two rays is called double refraction, and the ability of a crystal to separate the two refracted rays is measured by its birefringence. All anistropic crystals produce double refraction, but only a few have sufficiently strong birefringence to make the double refraction easily visible to the naked eye.

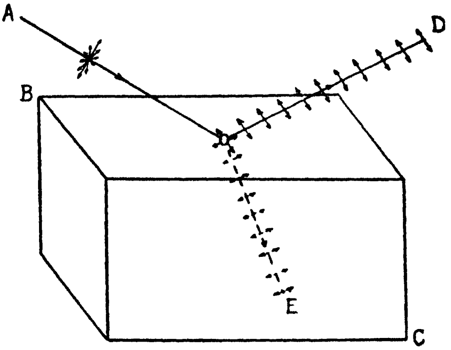

FIG. 124.—Polarization by reflection and refraction.

Experimental double refraction.—If a small dot is viewed through a superposed cleavage piece of clear calcite, two images of the dot are seen; on rotation of the calcite one image remains stationary while the other revolves about the first. The light which produces the fixed image is called the ordinary ray, *O*, since it travels through the calcite just as it would through a piece of glass. The light which produces the movable image is called the extraordinary ray, *E*, since it does not travel through the calcite as though it were glass. The paths of the two rays of light through the calcite are shown in a vertical section in Fig. 125, in which *A* is the object (or dot), *B* is the fixed image produced by the *O* ray, and *C* is the image produced by the *E* ray, which revolves about *B*. The two images have equal illumination, but are not at the same distance from the surface of the calcite. The *O* ray strikes each surface of the mineral at right angles and passes straight through; all the incident light is normal to the lower surface and yet part of it is refracted to form the *E* ray, which strikes the upper surface at an acute angle, but nevertheless leaves that surface at right angles. In short, the *E* ray is truly extraordinary in its apparent defiance of the law of refraction at each surface.

These two rays are completely polarized, so that they are vibrating only in two planes, the *E* ray in the plane of the paper and the *O* ray normal thereto, all vibrations being at right angles to the direction of propagation.[1] These facts may be verified by the use of a plate of tourmaline cut parallel with the vertical axis. Such a plate, like calcite, has the property of changing incident light (previously vibrating in all directions normal to its path) into two rays vibrating in planes at right angles to each other, and the additional property of absorbing, or being nearly opaque to, one of these rays, so that only light vibrating in a single plane (parallel with the vertical axis) is transmitted. If such a plate of tourmaline is superposed over the calcite with its vertical axis parallel with the long diagonal of the rhombic face of the calcite, only the image produced by the *O* ray is visible, as in Fig. 126; and if the tourmaline is turned at 90°, only the image due to the *E* ray is visible, as in Fig. 127. Therefore, the *O* ray is vibrating in the plane of the long diagonal of the calcite and the *E* ray is vibrating at right angles thereto, in a plane called the principal section, containing the ray and the vertical axis of the mineral.

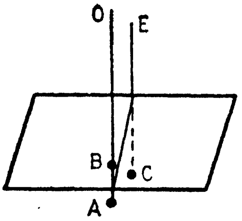

FIG. 125.—Double refraction.

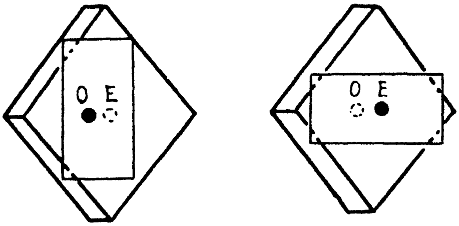

FIG. 126. FIG. 127.

FIGS. 126, 127.—Tourmaline over calcite.

Optic axis.—A detailed study of plates of calcite cut at various angles with the vertical crystallographic axis shows that one ray travels with constant velocity whatever the direction of transmission, while the other ray travels with different velocities in different directions, the variations being gradual and such that there is one direction (and only one) in which the velocities of the two rays are equal. This direction coincides with the vertical crystallographic axis, and is known as the optic axis. All the light traveling through the crystal exactly in this direction moves at the same rate, and, moreover, is not polarized. In crystals like calcite, the velocity of the *E* ray increases gradually from the optic axis until it reaches a maximum, which is the same for all directions of transmission normal to the vertical axis. The wave-front of light traveling as extraordinary rays in such a medium is an ellipsoid of rotation, whose axis of rotation is its minor axis and coincides with the vertical axis of the crystal. The wave-front of light traveling as ordinary rays in the same medium is a sphere which is tangent to the ellipsoid at the extremities of its minor axis. Crystals having wave-fronts of this kind, the sphere being inside of the ellipsoid, as in Fig. 129, are called optically negative or −. In other crystals, like quartz, the velocity of the *E* ray decreases gradually from the optic axis until it reaches a minimum which is the same for all directions of transmission normal to the vertical axis. The wave-front of light traveling as extraordinary rays in such a medium is an ellipsoid of rotation whose axis of rotation is its major axis. In such crystals the ellipsoidal wave-front is inside of the spherical wave-front, as in Fig. 128, and the mineral is said to be optically positive or +.

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[1] Only approximately correct for the extraordinary ray, as explained on p. 78.

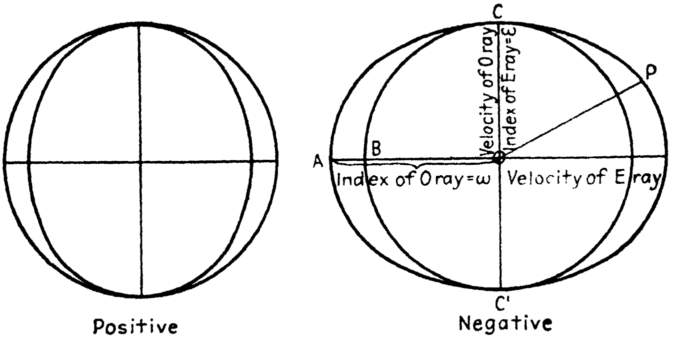

FIG. 128. FIG. 129.

FIGS. 128, 129.—Wave-fronts in uniaxial crystals.

Isoaxial, uniaxial, and biaxial substances.—In all isotropic substances, light travels with equal velocity in all directions, so that the wave-front is a sphere all axes of which are equal; such substances are therefore called *isoaxial.* Those anisotropic crystals in which one part of the light travels with uniform velocity and another part moves with a velocity varying in different directions are called *uniaxial*, since in them there is one "axis," or direction, parallel to which all the light travels with the same velocity. Those bodies in which both parts of the light travel with velocities which vary with the direction are called *biaxial*, because in them there are two "axes," or directions, parallel to which all the light travels with the same velocity.

Isometric crystals are isoaxial; tetragonal and hexagonal crystals are uniaxial; and other crystals are biaxial. Uniaxial crystals have one principal axis of symmetry which is the vertical crystallographic axis, parallel to which is the direction called the optic axis.

The index of refraction of a uniaxial crystal for the *E* ray varies with the direction of transmission, from equality with the index for the *O* ray in the direction of the optic axis, to its greatest deviation from this value in the direction normal to the vertical axis. The latter value is always implied when the index is referred to without statement of the direction; it is denoted by N_e or by the Greek letter epsilon (ϵ). The index for the *O* ray is denoted by N_o, or by the Greek letter omega (ω).

The indices of refraction of two isotropic substances are inversely proportional to the velocities of light in them; also, the two indices of a uniaxial crystal are inversely proportional to the velocities of the two rays in that substance. Therefore, in negative crystals, in which the *E* ray travels faster than the *O* ray, the index of refraction for the *O* ray is more than that for the *E* ray, or $\omega > \epsilon$. In positive crystals, in which the *O* ray travels faster than the *E* ray, the index of refraction for the *O* ray is less than that for the *E* ray, or $\omega < \epsilon$.

In a negative crystal, the velocity of the *E* ray traveling at right angles to the optic axis is represented by half the length, *OA*, of the major axis of the ellipse, and that of the *O* ray is represented by half the length, *OC*, of the minor axis, or by the radius of the circle in Fig. 129. Further, *OA* is the direction of transmission and also represents the velocity of the *E* ray which vibrates in the direction *OC* and for which the index of refraction is represented by *OC* (which is proportional to $1/OA$). Similarly, *OC* is the direction of transmission and also represents the velocity of the ray which vibrates in the direction *OA*, and for which the index of refraction is represented by *OA* (which is proportional to $1/OC$).

Finally, an extraordinary ray traveling in an indefinite direction, such as *OP*, has a velocity represented by *OP*, and an index represented by $1/OP$. Since the area enclosed by the tangents and the conjugate diameters of an ellipse is a constant (which may be assumed equal to one) it may be shown that $1/OP$ is equal to RN of Fig. 169. If a tangent to the ellipse be drawn at the point where any ray meets it, this tangent represents the wave-front of the light and a direction at right angles to this is known as the wave-normal. For example, OW of Fig. 169 is the wave-normal of the ray OP. It is believed that the direction of vibration of any extraordinary ray is at right angles to its wave-normal and therefore not exactly normal to the ray.

Since one axis of the ellipse is equal to the diameter of the circle, all parts of the wave-fronts are known if the ellipsoid alone is constructed, as may be done directly from the indices of refraction. Such a figure is called the index-ellipsoid or indicatrix.

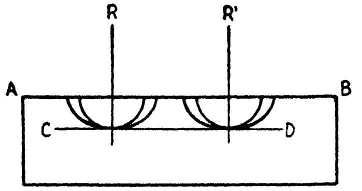

FIG. 130.—Light incident normally on a basal plane.

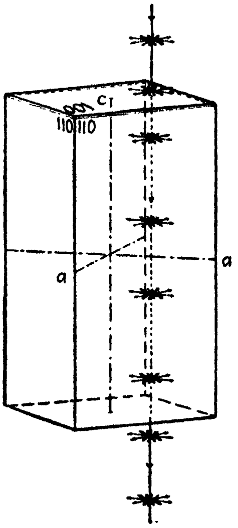

FIG. 131.—Ray parallel to vertical axis.

Double refraction in uniaxial crystals.—By proper use of the wave surfaces, the paths of the ordinary and extraordinary rays may be constructed for light of any known angle of incidence on any crystal surface. Beginning with the simplest case, the light may be incident normally upon the basal plane, for example, of a negative crystal. Since the optic axis is a direction and not a line of fixed position, the line representing the optic axis in the figure of wave surfaces may always be assumed to meet the surface at the point of incidence of any ray; and, since the light will be assumed to be moving forward and not in both directions from a point, the surface of incidence may be assumed to pass through the center of the figure of wave surfaces.

Then, in Fig. 130, a beam of parallel rays, including *R* and *R'*, strikes the basal plane, *AB*, at right angles, and each ray moves onward without division and without refraction, since the ordinary and extraordinary wave-fronts coincide for these rays and *CD* is the wave-front of all the transmitted light within the crystal. The condition of light transmitted in this way is shown in Fig. 131.

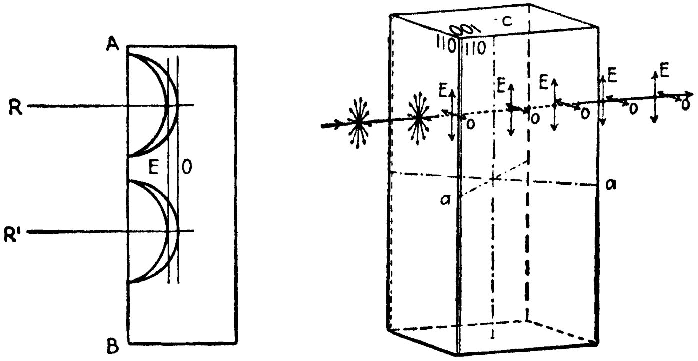

Fig. 132. Fig. 133.

Figs. 132, 133.—Effect of a positive uniaxial crystal on light striking a vertical plane at right angles.

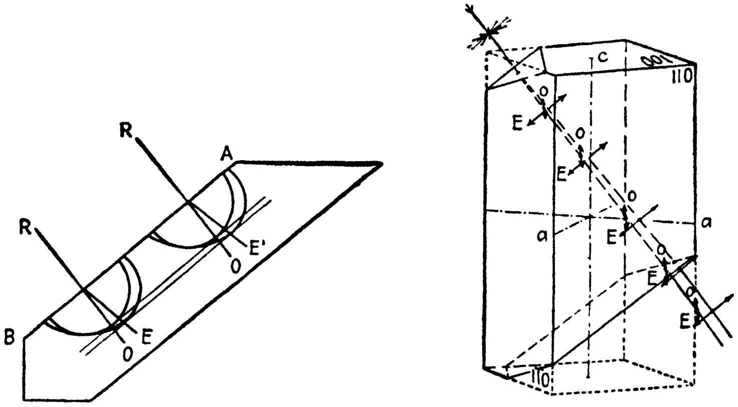

Fig. 134. Fig. 135.

Figs. 134, 135.—Effect of a negative uniaxial crystal on light striking a pyramidal surface at right angles.

Second, assuming that the light is incident at right angles upon a vertical face of a positive crystal, a beam of light, *RR'*, strikes the prism face, *AB*, normally, as in Fig. 132. The wave-surface figures show that while the *O* and *E* rays follow a common path with no refraction they travel at unequal velocities; they are vibrating in single planes at right angles to each other, as shown in Fig. 133. Neither ray is "extraordinary" in the sense of not obeying the ordinary law of refraction at the surfaces, but the *E* ray has a velocity not equal to that of the light traveling parallel to the vertical axis in the preceding case.

Third, assuming that the light is incident at right angles upon a face of indefinite orientation of a negative crystal, in such a way that the plane of incidence is parallel with the optic axis, a beam of light, *RR'*, strikes the pyramidal surface, *AB*, normally, as in Fig. 134. The wave-surface figures show that, while the ordinary light passes through without refraction, the extraordinary rays are refracted. The refraction of the *E* rays renders them less nearly parallel with the optic axis than the *O* rays in negative crystals, as in Fig. 134, and more nearly parallel in positive crystals. The two rays travel with unequal velocities and are polarized in planes at right angles to each other, as shown in Fig. 135.

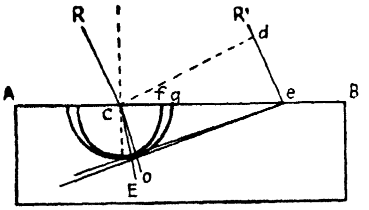

FIG. 136.

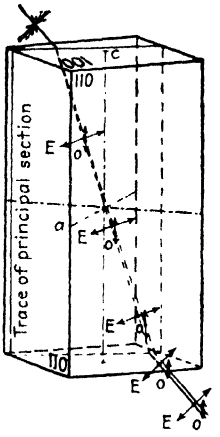

FIG. 137.

FIGS. 136, 137.—Effect of a positive uniaxial crystal on light striking a basal plane obliquely, the plane of incidence being parallel to the optic axis.

Fourth, if a beam of light, *RR'*, is incident obliquely on the basal plane, *AB*, of a positive mineral, in such a way that the plane of incidence includes the optic axis, as in Fig. 136, the paths of the refracted rays may be found by the use of Huyghen's construction, as before. The wave-front of the *O* ray in the crystal, from the point *C* at the moment the ray *R'e* reaches *e*, is found by drawing the section of a sphere whose radius is to *de* as the velocity of light in the mineral is to its velocity in air, and drawing a tangent from *e* to this circle. The wave-front of the *E* ray in the crystal is similarly found by constructing the section of an ellipsoid of rotation whose shorter axis is at right angles to the optic axis, and whose two axes are given by the proportion, $cf : cg = V_e : V_o = \frac{1}{N_e} : \frac{1}{N_o}$, and then drawing a tangent from e to this ellipse. The paths of the two rays, their relative velocities, and their directions of vibration are shown in Fig. 137 for a positive mineral.

Fifth, assuming that a beam of light, *RR′*, strikes obliquely a vertical plane, *AB*, of a negative mineral, in such a way that the plane of incidence is parallel with the vertical axis, as in Figs. 138 and 139, or normal to the optic axis, as in Figs. 140 and 411, the paths of the two rays produced may be constructed in a manner wholly similar to that used in the last case. The double refractions, relative velocities, and polarization of the two rays in planes at right angles to each other are shown in Figs. 139 and 141. In Fig. 140 the optic axis is normal to the plane of the paper; therefore the sections of both wave surfaces are circles. It may be noted that the *E* ray is refracted more than the *O* ray in Fig. 138 and less than the latter in Fig. 140, though both figures represent negative crystals. It is evident that at some intermediate position of the plane of incidence the *E* ray must be refracted at the same angle as the *O* ray. It does not follow that the two rays will in this case coincide; they do not coincide because the *E* ray is refracted out of the plane of incidence in which the *O* ray remains.

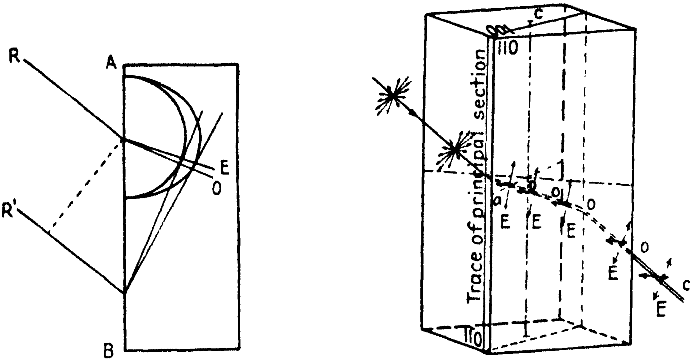

FIG. 138. FIG. 139.

FIGS. 138, 139.—Effect of a negative uniaxial crystal on light obliquely incident on a vertical plane, the plane of incidence being parallel to the optic axis.

Sixth, assuming that a beam of light, *RR'*, is incident obliquely on a surface, *A B*, of indefinite position on a negative crystal, in such a way that the plane of incidence is parallel with the optic axis as in Fig. 142, the paths of the two rays may be constructed by the same methods. The double refraction, relative velocities, and polarization of the two rays in planes at right angles to each other are shown in Fig. 143.

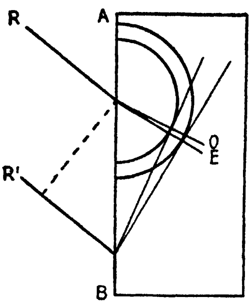

FIG. 140.

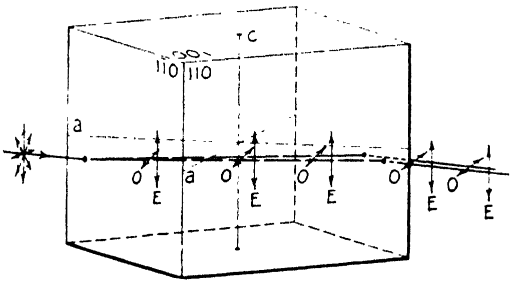

FIG. 141.

FIGS. 140, 141.—Effect of a negative uniaxial crystal on light obliquely incident on a vertical plane, the plane of incidence being normal to the optic axis.

Seventh, if the plane of incidence is not parallel with the optic axis, the plane of the drawing will not cut the ellipsoidal wave surface of the extraordinary ray symmetrically, and therefore the point of tangency of the plane wave-front with the ellipsoid will not lie in the plane of

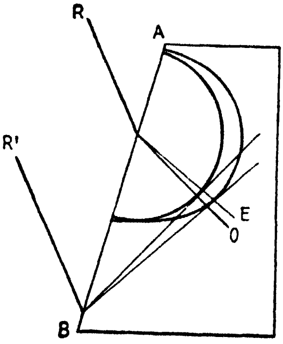

Fig. 142.

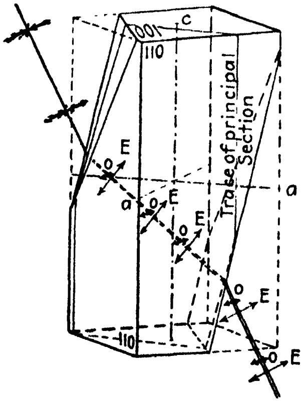

FIG. 143.

FIGS. 142, 143.—Effect of a negative uniaxial crystal on light obliquely incident on a surface of indefinite position, the plane of incidence being parallel with the optic axis.

incidence which is the plane of construction in which the *O* ray lies. In such a case a three-dimension figure is needed to determine the path of the *E* ray.

As previously stated, the extraordinary ray does not obey the law of refraction; but the wave-normal of the extraordinary ray always occupies such a position that the index of the crystal for the extraordinary ray in the given direction is equal to the sine of the angle of incidence divided by the sine of the angle between the wave-normal and the normal to the surface. That is, if ϵ' is the index for the extraordinary ray in a special direction and R is the angle between the wave-normal of that ray and the normal to the surface:

$$\epsilon' = \frac{\sin\ i}{\sin\ R}.$$

Absorption and pleochroism.—Isoaxial crystals reduce by absorption the amount of light of various wave lengths reflected or transmitted, and the proportion of the light absorbed has no relation to crystalline form or direction. If the amount of absorption is sufficient to be perceptible the crystal is darkened and usually colored.

Uniaxial crystals may modify the amount and kind of light transmitted or reflected, and the modification may be quite different for the two rays into which the transmitted light is divided. The crystal may absorb much more of one ray than the other; the fact is most briefly expressed by an "absorption formula"; for example, tourmaline absorbs the *O* ray more than the *E* ray, or, in tourmaline, $O > E$. Also, the kind of light absorbed in the two rays may differ; thus, the unabsorbed part of the *O* ray from one variety of tourmaline is dark green, while the unabsorbed part of the *E* ray is reddish violet. This is expressed in a "pleochroism formula" as follows: O = dark green, E = reddish violet.

The extraordinary ray in a uniaxial crystal vibrates in the principal section, that is, in a plane containing the incident ray and the optic axis, while the *O* ray vibrates in a plane at right angles to the principal section. Also, all incident light vibrating in the principal section passes through the crystal as extraordinary rays. Therefore, if white light vibrating in a single plane before incidence passes through a crystal of tourmaline, the color of the transmitted light depends upon the relative position of the plane of vibration of the incident light and the optic axis of the mineral.

DIRECTIONS FOR LABORATORY WORK

Observe double refraction by looking through a cleavage piece of calcite. Look at a single dot; rotate the calcite. Notice the relation between the line connecting the two images and the shorter diagonal of the rhombic face. Find the optic axis of the calcite. Assuming that the rhombic faces are of equal size, the vertical axis connects the two trihedral solid angles. Is the principal section parallel or at right angles to the shorter diagonal of the rhombic face? Do both images revolve? Is the distance between the dots related to the thickness of the calcite? How? Superpose another piece of calcite over the first, and, on rotation (avoiding scratching of the pieces), notice that four images are visible in many positions. Explain this fact by one or more drawings. Draw a vertical section through the calcite showing the paths of the two rays and also the position of the optic axis. Is the extraordinary ray refracted so as to be more or less nearly parallel with the optic axis than the ordinary ray?

CHAPTER V

UNIAXIAL CRYSTALS IN PARALLEL POLARIZED LIGHT

THE addition of a nicol to produce polarized light increases the usefulness of the microscope for studies of crystals many fold. For certain purposes a condensing lens must be used above the polarizer to render the polarized light either convergent or divergent. For many other purposes no such lens is necessary, and for certain work it is imperative that it be removed, and the light taken from a distant source, such as the sky, so as to be as nearly parallel as possible.

It is important to understand fully the action of the polarizing microscope upon parallel polarized light. If a section or fragment of the uniaxial mineral is in place between crossed nicols, the light is, in general, double refracted and plane polarized three times. These facts are illustrated diagrammatically in the vertical section and plan of Figs. 144 and 145. After reflection from the mirror *M*, the ray of light enters the lower nicol, *IJ*, where it is doubly refracted, and completely polarized, one ray (the extraordinary) vibrating in the principal section, which is the plane of the paper in the drawing, and the other ray vibrating normal thereto. The *E* ray vibrates in the direction *PP′* of the plan and the *O* ray in the direction of *AA′*. The *O* ray is totally reflected by the Canada balsam to the black surface at *W*; only the *E* ray passes through the polarizer.

When this ray strikes an anisotropic crystal section, as *SS′*, cut in an indefinite direction, it is, in general, divided into two rays, which may be called the ordinary (*O′*) and extraordinary (*E′*) rays for this crystal. In the drawing the crystal is supposed to be uniaxial and the *O′* ray is not refracted, since the incidence is normal. In general, in biaxial crystals, both rays are refracted. The rays *O′* and *E′* vibrate in planes at right angles to each other, the *E′* ray vibrating in the principal optic section of the crystal, which may be assumed to be in the position *BB′* in the plan, while the *O′* ray vibrates in the direction *CC′*. These two rays pass upward to the analyzer *RT*, where the third double refraction produces two rays from each of them. In the vertical section, the portion above XY is a section at right angles to the lower portion and in the direction AA' in the plan. If DO be taken to represent the vibration of the E ray after passing the polarizer, the two rays, O' and E', produced by the crystal have vibrations that may be represented by OG and FO respectively. In the upper nicol the ordinary ray (O'') derived from O' has a vibration represented by NO, and that (O''') derived from E', a vibration represented by HO. Also the extraordinary ray (E'') derived from O' has a vibration represented by LO, and that (E''') derived from E', a vibration represented by KO. Now the two ordinary rays (O'' and O''') are totally reflected to the dark wall of the upper nicol; therefore their vibrations, NO and HO, disappear. But the two extraordinary rays (E'' and E'''), whose vibrations are represented by LO and KO, pass through the analyzer; and, since their vibrations are in the same plane and have a fixed phase relation, they "interfere" or combine. In monochromatic light this interference produces variation in the intensity of the light, depending upon the difference of phase of the two rays. As explained later, if the rays have no difference of phase, or if one is retarded an integral number of wave lengths behind the other, the amplitude of the resultant wave is zero, and darkness results. If the rays have a difference of phase of

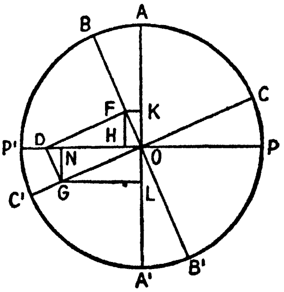

FIG. 144.

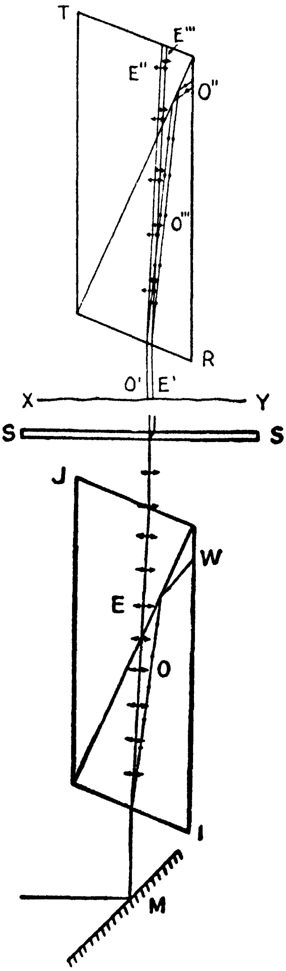

FIG. 145.

FIGS. 144, 145.—Effects of a polarizing microscope on light.

one-half wave length, or any uneven multiple thereof, the interference doubles the amplitude and quadruples the intensity. In white light, since the different colors constituting the light have different wave lengths the retardation which one ray suffers has different relations to the different colors, causing some to be in opposite phase and others to differ by an integral number of wave lengths; therefore, interference reduces the intensity of some colors (even to zero, as a limit), while increasing the intensity of others; thus, interference produces colors from white light. The color produced depends upon the difference of phase, or the relative retardation, and this in turn depends upon the birefringence of the crystal concerned, the direction in which the light travels through the crystal with respect to the optic axis (or optic axes), and the thickness of the section or fragment.

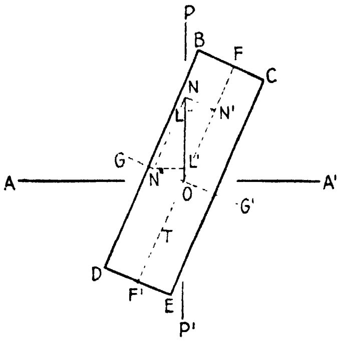

FIG. 146.—Vibration directions.

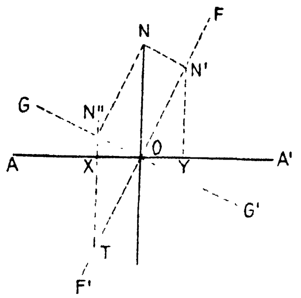

FIG. 147.—Vibrations in the analyzer.

In the simple combination of two light waves (without the microscope), darkness results when the phase difference is half a wave length, but when monochromatic light passes through crossed nicols and through a crystal between them, darkness results when the phase difference produced by the crystal is one wave length. This fact needs explanation. In Fig. 146 let PP' represent the plane of vibration of light which passes through the lower nicol or polarizer; upon entering a crystal $BCDE$, whose planes of vibration are FF' and GG', the vibration of a particle at O, which may be assumed to be at its crest at N, is resolved into two components, ON' and OM''. If these two waves pass through the crystal so as to have, at emergence, no difference of phase, or a difference of phase of any integral number of wave lengths, the wave ON'' will be at its crest N'' when the wave ON' is at its crest, N'. If, in passing through the crystal, they acquire a difference of phase of half a wave length, or any uneven multiple thereof, the wave ON'' will be at N'' when the wave ON' is at its trough, T.

Whatever the difference of phase which results from the difference in path and difference in velocity of the two waves in the crystal, when they enter the upper nicol, whose vibration plane is AA', each will be resolved into two components one of which, in the plane PP', will be totally reflected and absorbed in the walls of the analyzer, while the other, in the plane AA', will pass through the upper nicol. If they have a difference of phase of one wave length, the components which will be absorbed may be represented by OL and OL'. The more important components which pass through the analyzer are shown in Fig. 147 at OX and OY, which will be their positions if the phase difference is any integral number of wave lengths. It is clear that OX and OY are equal and opposite in direction; therefore, these two waves will destroy each other and darkness will result if monochromatic light is being used. Also, if the difference of phase is half a wave length (or an uneven multiple thereof), when the wave vibrating in the plane GG' is at N'' the wave vibrating in the plane FF' will be at T, and the components of these waves vibrating in the plane AA' will be two waves (each OX) of equal amplitude and acting in the same direction; therefore, the resultant wave will have double the amplitude and four times the intensity.

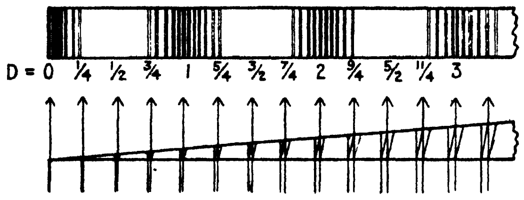

FIG. 148.—A wedge between crossed nicols.

Whenever the difference of phase is neither a wave length nor a half wave length (nor a multiple thereof), the components in the plane AA' will be unequal, and the resultant will always have some amplitude varying between the limits named.

The difference of phase produced by any crystal depends upon the difference in velocity and the difference in path of the two waves within the crystal, and the latter varies with the thickness of the section (or fragment). Accordingly, a wedge-shaped section of a crystal will produce a difference of phase varying from zero at the thin edge to any desired amount at the other end. Hence, a wedge will alternately produce darkness and light upon its gradual insertion between crossed nicols, when monochromatic light is used. In Fig.

148, the relation between the thickness of the wedge and the difference in phase is shown; the difference in phase *D*, is expressed in terms of fractions of the wave length, λ, of the light used. The thickness necessary to produce a given difference in phase varies with the mineral used, and also depends upon the way in which the wedge is cut, that is, the relation in position between the path of the light and the optic axis in the wedge.

When white light is used, the difference of phase must be measured in some other unit than the wave length, because white light has no definite wave length, but consists of waves whose length varies from about 380 to about 760 millionths of a millimeter, sometimes expressed as 380 to 760 millimicrons, or 380 to 760 mμ. In Fig. 149, the difference of phase, *D*, is given in millionths of a millimeter. The same figure shows the effect of any difference of phase from zero to 2000 mμ on various kinds of monochromatic light. For each color a medium value of the wave length is chosen as follows: violet, 410 mμ; blue, 460 mμ; green, 510 mμ; yellow, 565 mμ; orange, 620 mμ; red, 690 mμ. When white light is used, the effect produced depends upon the relation of the dif-

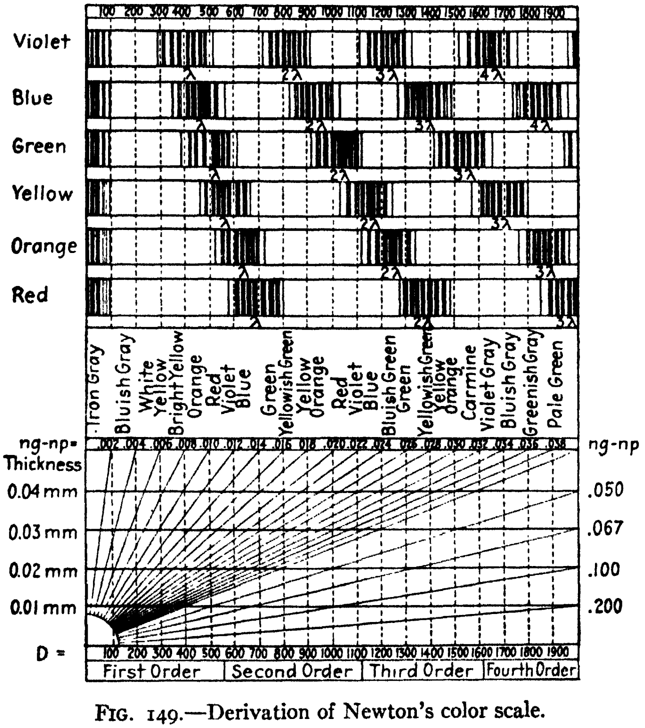

FIG. 149.—Derivation of Newton's color scale.

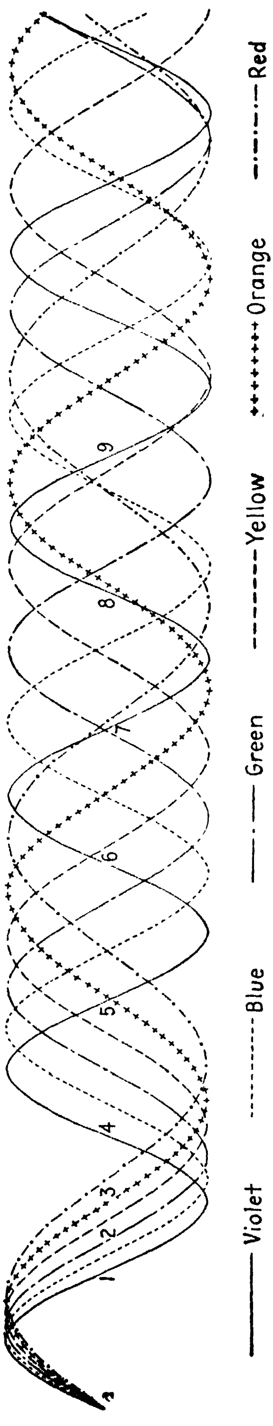

Fig. 150.—Certain wave lengths of light.

ference of phase to wave lengths of all parts of the white light; all these parts are approximately represented by the colors selected. Accordingly, the effect may be inferred by a study of the upper part of Fig. 149; it is modified somewhat by the fact that the intensity of various parts of the spectrum varies considerably, being greatest for yellow and least for violet. With no difference of phase, all parts of white light destroy each other in the upper nicol, as illustrated in Fig. 147 and darkness results. From the same figure it is clear that the intensity of the light increases as the difference of phase increases; accordingly, as D varies from 0 to 260 mμ, the effect varies from darkness to white

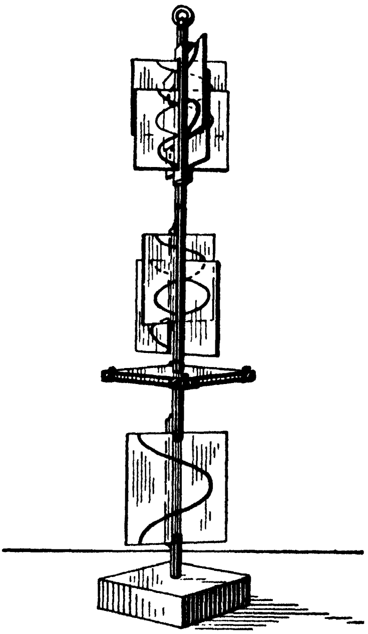

Fig. 151.—Model illustrating the effect of a polarizing microscope on light.

light; at 300 mμ yellow light is produced, since yellow is near its maximum ($\frac{1}{2}\lambda$ for yellow) and violet is partly destroyed. At 400mμ violet is wholly destroyed and blue and green are much weakened; yellow is considerably past its maximum, but on account of its greater relative intensity it dominates over red; for the same reason orange is found at 450 mμ and red at 530 mμ. At 575 mμ violet is produced, since green, yellow, and orange are practically destroyed, and the red and blue simply combine to increase the intensity of violet.

Another method of obtaining an understanding of the way in which interference produces colors from white light is by studying Fig. 150, which represents certain wave lengths of each important color of white light in their proper relations. By making a tracing of this drawing and then moving the point *O* of the tracing to points such as 1, 2, 3, etc., of the drawing, it is possible to see the effect on each color of various amounts of retardation.

A model,[1] such as shown in Fig. 151, is useful in studying the effect of a polarizing microscope on light. The vertical rod is divided into several parts, which may be rotated independently. The lowest celluloid plate represents the vibration plane of the lower nicol with a ray of light represented on it. The transverse plate next above represents the stage of the microscope carrying a crystal section; it may be rotated to bring the vibration planes of the crystal into any desired relation to that of the polarizer. The celluloid plates next above represent the vibration planes of the crystal and the rays vibrating in them; they rotate together, remaining at right angles; one is set half a wave length ahead of the other, but can be set at any other small amount; the four celluloid plates near the top represent four rays in the analyzer, only two of which pass through; they rotate together, and two are shown half a wave length ahead of the other two. The way in which the microscope introduces the equivalent of half a wave length retardation is readily seen by the use of this model.

The colors from darkness to the first violet are known as colors of the first order; and violet at the "upper" end of the order is called the sensitive tint, because a slight change in difference of phase produces, in this region, a decided change of hue, to which the eye is very sensitive. At 660 mμ, blue is produced, since yellow, orange, and red are nearly extinguished and green and violet combine to reinforce the blue, which is near its maximum. At 750 mμ, green is produced, violet and red being nearly destroyed and blue and orange merely adding to the green. Yellow, orange, and red follow in order. At 1125 mμ the second violet marks the upper limit of the second order. From this point the colors are repeated in the same order: violet, blue, green, yellow, orange, red. The colors of the third order are somewhat paler than those of the second, and in the fourth order they are still less distinct, being mixed with white; above the fourth order, pale greenish and reddish grays mark the transition to white of the higher order, not readily distinguishable from ordinary white light. This white results from the fact that as the difference of phase increases it gradually reaches values which are uneven multiples of one-half the wave length of colors in all parts of the spectrum, the intensities of which are therefore increased; a mixture of waves taken regularly from each color of the normal spectrum produces light closely similar to white. To illustrate, if the difference of phase is 5300 mμ, it is equal to:

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[1] See F. E. Wright: *Am. Jour. Sci.*, CLXXVI, 1908, p. 536.

15 times ½ of 707 mμ, a wave length in red.
17 times ½ of 623 mμ, a wave length in orange.
19 times ½ of 558 mμ, a wave length in yellow.
21 times ½ of 505 mμ, a wave length in green.
23 times ½ of 461 mμ, a wave length in blue.
25 times ½ of 424 mμ, a wave length in violet.

Abnormal interference colors are produced by uniaxial crystals in various ways. If the crystal absorbs part of the light so as to be colored when the upper nicol is not in use, the color observed when it is seen between crossed nicols will be due to the combined effect of the interference color and the color due to absorption. Further, the birefringence of any anisotropic crystal is not exactly the same for all parts of the spectrum; for most kinds of crystals the differences in the birefringence for different parts of the spectrum are not sufficiently great to produce noticeable effects; but in a few kinds of crystals these differences result in very peculiar interference colors. Thus, if a crystal has zero birefringence for one color and appreciable birefringence for other colors, the former color will be lacking in all the interference colors produced by the crystal, no matter what its thickness may be. For example,[2] melilite is often nearly isotropic for yellow light, and the interference color is a dark blue, called "ultra blue." It may be distinguished from blue of the normal series of interference colors by superposing a mica plate or sensitive tint plate, the method of using which will be described later. It will be found that the ultra blue color is produced although the difference of phase is only 100 $m\mu$, to 200 $m\mu$, instead of 660 $m\mu$ or 1175 $m\mu$. In biaxial crystals abnormal interference colors may also result from the fact that the extinction position is not exactly the same for all colors, or from the fact that the crystal is uniaxial for some special color and biaxial for all others.

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[2] Another example is furnished by torbernite (air dried) which is isotropic for green light and weakly birefringent for other colors (+ in red and − in blue light) giving abnormal purple (red to blue) interference colors (N. L. Bowen: *Am. Jour. Sci.*, XLVIII, 1919, p. 195).

Factors determining interference colors.—The interference color produced by any crystal depends directly upon the difference of phase produced by the crystal, and this, in turn, depends upon three factors, namely, (1) the birefringence of the crystal, measured by the difference between ω and ϵ; (2) the thickness of the crystal in the direction taken by the light, and (3) the direction in which the light passes through the crystal with reference to the optic axis. If light travels in a crystal at right angles to the optic axis, the relative velocities of the two rays are inversely proportional to the indices, ω and ϵ: accordingly, the difference of phase for a given thickness varies directly with the difference between the indices. If the two rays travel at unequal velocities through a greater thickness, it is evident that the difference of phase is increased. Finally, if light travels through a crystal at an acute angle with the optic axis, the extraordinary ray has an index, ϵ', nearer to ω in value than is ϵ; therefore, the difference of phase produced by a given thickness is less than when the light travels at right angles to the optic axis, since the difference of phase is proportional to the difference between the indices.

Further, if parallel light is incident at right angles upon a basal section of a uniaxial crystal, all parts have the same index, since ϵ' is equal to ω, as shown in Figs. 109 and 110, and the light is not doubly refracted nor polarized, but passes through the section as it would through an amorphous or an isometric substance. Therefore, such sections are dark between crossed nicols in all positions of rotation; light from the lower nicol does not have its vibration plane changed, and is all cut off by the analyzer.

Determination of order of interference color.—Any given color, except gray at the lower end of the first order, is found at least twice in the color scale, but only once in any single order. The precise shade of a color, say red, in one order is not exactly the same as in another order, but this difference is not sufficient to enable the order to be distinguished, especially by the beginner. There are two methods of determining the order to which a color belongs; one is by means of the quartz wedge, the other is by means of a beveled edge.

The quartz wedge is a wedge-shaped plate of quartz, like Fig. 148, but with its vertical axis parallel with the glass plates between which it is mounted. It is usually marked "quartz wedge," or "compensator"; the arrow at one end indicates the direction of vibration of the slow ray. When the quartz wedge is to be used to determine the order of an interference color, the crystal producing the color should be turned to a position at 45° from extinction, and the wedge should be inserted, thin edge forward, in the path of the light above the crystal. This will cause a series of changes in the interference color observed, due to an increase or a decrease in the total retardation of one ray as compared with the other. It is convenient to call the ray which is more retarded in any anisotropic substance the slow ray, or the Z ray, in that medium, and to call the other ray the fast ray, or the X ray. If the slow ray in the crystal is the slow ray in the wedge, as in Fig. 153, the colors observed will be in the order obtained by reading the colors of Newton's scale (Fig. 149) from left to right, and the colors are said to "rise," since they pass to higher orders. If the slow ray in the crystal is the fast ray in the wedge, as in Fig. 152, the colors obtained will be in the reverse order. If the first result is secured, the stage should be turned 90°; then the insertion of the wedge as before will give the second result. When this is obtained the wedge should be inserted far enough to cause the colors to "fall" to the dark gray at the lower end of the first order. Since this color occurs in only one place in the scale the order to which it belongs is not in question. To obtain the order of any other interference color it is only necessary to find its relation to this dark gray. This may be done by listing the interference colors, as they are observed, from the original color, produced by the mineral alone, to the dark gray, or *vice versa*. Thus, if the list reads: red, yellow, white, dark gray, the interference color, red, belongs to the first order, while if it is: red, orange, yellow, green, blue, red, yellow, white, dark, gray, the original color belongs to the second order, as may be readily seen by studying the series in Newton's scale (Fig. 149).

When the darkest (gray) color is obtained, the retardation of one ray caused by the crystal is balanced by the acceleration of the same ray produced by the wedge, and the wedge is said to *compensate* the crystal; the wedge is said to be at the *compensation point.*

The beveled edge, when present, is a simpler means of determining the order of an interference color. It can only be used when the crystal under examination has, somewhere along its border, an edge (in contact with balsam or a substance of weak birefringence) sufficiently

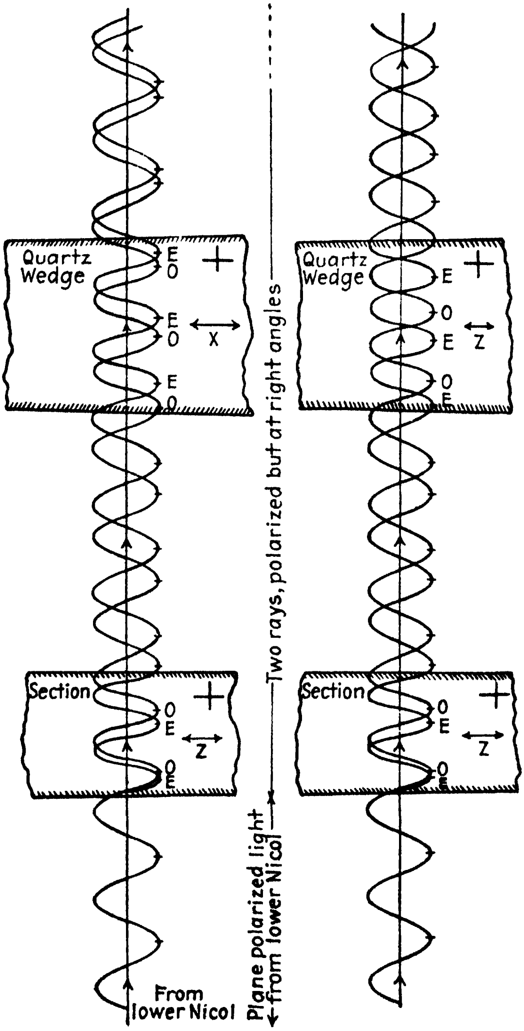
Quartz Wedge
E
O
+
X
Section
Z
From lower Nicol
Two rays, polarized but at right angles
Plane polarized light from lower Nicol

FIG. 152. FIG. 153.

FIGS. 152, 153.—Diagrams showing the action of the quartz wedge.

beveled to produce a series of colors similar to those caused by an artificial wedge. It is only necessary to observe the relation between dark gray of the first order and the interference color produced by the full thickness of the crystal, as shown by the series of colors between them on the beveled edge, to determine the order to which the given color belongs. For example, if the crystal, *a*, in Fig. 154, gives a yellow interference color over the surface where it is of full thickness, as at 1, and if it produces a series of colors on a beveled edge that are as follows: 2, green; 3, blue; 4, red; 5, yellow; 6, white; 7, dark gray, the yellow interference color found over the main surface belongs to the second order. Frequently, the beveled edge is very narrow, so that it is impossible to distinguish all the colors; but, since red is the highest color of each order, if a single red band can be seen on the bevel, the color of the main surface is of the second order (or higher); if two red bands can be seen on the bevel, the main color is of the third order (or higher).

Measurement of birefringence.—The birefringence of a crystal is always measured by the difference between its greatest and least indices of refraction, that is, with uniaxial crystals, the difference between ω and ϵ. The extraordinary ray has the index ϵ, only when it is traveling at right angles to the vertical or optic axis. When propagated in any other direction it has an index, ϵ', nearer to ω than ϵ is. Therefore, a grain of a uniaxial crystal must lie so that light travels through it normal to the optic axis in order that the indices of refraction may be ω and ϵ. The birefringence of a given crystal or grain, as cut in a section, is less than the birefringence of the substance of which it is a sample, except when the given crystal or grain lies with its optic axis (or, in biaxial crystals, both optic axes) parallel with the object glass and with the same exception it is measured by the difference between ω and ϵ', which is always less than the difference between ω and ϵ.

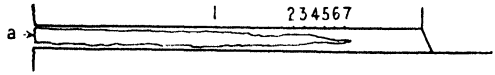

FIG. 154.—Magnified section through a crystal section.

The difference between the two indices, ω and ϵ, may be determined by accurate measures of those indices themselves, or it may be estimated from its effect in producing an interference color. The interference color produced by a given crystal or grain depends upon (1) the direction in which the light passes through the crystal or grain with reference to the optic axis, (2) the birefringence of the substance, (3) the thickness of the grain or section. In a given thin section of uniform thickness, the crystals or grains which lie so the glass slide is exactly parallel with the optic axis produce the highest interference color shown by any crystals or grains of a given substance.

The birefringence of a uniaxial crystal is measured by the difference between its indices, ω and ϵ. Either of these indices may be the greater index; it is convenient to have symbols for the greater index and the smaller index. The greater index is represented by N_g, and the smaller index by N_p, the subscripts referring to " great " and " petty " or small. When the light travels at right angles to the optic axes, so that the two rays have their maximum difference of velocity, the index of refraction for the slow ray is N_g and that for the fast ray is N_p.

Relative velocities of transmitted rays.—Light passing through any uniaxial crystal not parallel with the optic axis is divided into two rays (if the crystal is not at extinction) which vibrate in planes at right angles to each other and travel with unequal velocities. The retardation of the slow (Z) ray as compared with the fast (X) ray determines the interference color produced between crossed nicols, as already explained. If the retardation of the slow ray be increased, the interference color " rises " in the color scale, that is, it changes in the direction of the higher orders of the scale. If the retardation be decreased, the interference color " falls," that is, it changes toward darkness, which is considered the bottom of the scale. If a plate, in which the direction of vibration of the slow ray is known, is superposed over a grain or a section so that the vibration planes coincide, the interference color rises, provided the plane of vibration of the slow ray in the grain or section is parallel with the plane of vibration of the slow ray in the plate, so that the same ray which is retarded in the grain or the section is further retarded in the plate. The interference color falls, provided the plane of vibration of the slow ray in the grain or section is parallel with that of the fast ray in the plate, so that the ray which is retarded in the grain or section is advanced in the plate. Consequently, by properly superposing such a plate over any crystal, the position of the plane of vibration of the slow ray can be distinguished from that of the fast ray. This may be accomplished by means of: First, the quarter undulation mica plate; second, the sensitive tint plate, or third, the quartz wedge. In all these plates the arrow marks the position of the plane of vibration of the slow ray. The mica plate consists of a thin cleavage film of colorless mica of such thickness as to produce a retardation of a quarter of a wave length of yellow (sodium) light, that is, about 150*mμ*. It is usually mounted between glass plates and marked " mica " or $\frac{1}{4}\lambda$. Except with crystals producing very low or very high interference colors the mica plate is very convenient. For crystals giving very low interference colors the sensitive plate is most useful, while for those exhibiting very high interference colors the quartz wedge must be used. These plates must be used with their vibration planes not parallel with the planes of the nicols.

Elongation and flattening.—Many crystals are much longer in one direction than in any other direction, and such a direction of elongation is easily seen microscopically. Thus, apatite is commonly elongated in the direction of the vertical axis, and fibrous crystals are still more elongated. Nearly all uniaxial crystals, which exhibit elongation, have the vertical axis parallel to their long direction. Whenever a crystal under examination exhibits distinct crystal outline with one direction several times as long as any other, this direction may be used as a basis of reference, and the relation to it of the vibration directions of the fast and slow rays may be determined. Whenever the vibration direction of the slow ray (Z) is exactly parallel, or more nearly parallel, than that of the fast ray (X), to the direction of elongation, the elongation is said to be positive. If the fast ray is more nearly parallel to the elongation, the sign of elongation is said to be negative.

Another crystal habit which is very common in some substances consists in an elongation in all directions parallel to a given face, or in a flattening parallel to that face. This is well illustrated by lamellar crystals, like tridymite and calomel. In uniaxial crystals, flattening is, in nearly all cases, parallel to the basal pinacoid. Sections of such crystals across the plane of flattening appear to be elongated in directions in that plane which are determined by the intersection of the plane of the section with that of the flattening. As in the preceding case, whenever the direction of vibration of the slow ray is more nearly parallel to the direction of apparent elongation (in the plane of flattening) the sign of elongation is said to be positive, and when X occupies this position the sign of elongation is said to be negative. Since the direction of apparent elongation is indefinite in this case (being any direction in a plane), the sign of elongation may be better described as positive when the fast ray vibrates more nearly at right angles to the plane of flattening than the slow ray, and as negative when the slow ray vibrates in this direction.

Extinction position.—If the crystal in Fig. 146 be supposed to be rotated about an axis perpendicular to the paper at O, a study of the figure shows that the component waves in the plane AA' have their maximum amplitude when the vibration planes (FF' and GG') of the crystal bisect the angles between the vibration planes (PP' and AA')

of the nicols, and their minimum (zero) amplitude when the vibration planes of the crystal coincide with the vibration planes of the nicols. With zero amplitude of the waves vibrating in the plane of transmission of the analyzer, no light passes through, and darkness, or extinction of light, takes place.

It is evident that the rotation of the crystal, just described, may be conveniently accomplished by rotating the stage of the microscope carrying the plate. Four times in a complete rotation the vibration planes of the crystal coincide with the vibration planes of the nicols, and darkness, or extinction, results. The angle between successive positions of extinction is necessarily 90°, since the vibration planes of the crystal and those of the nicols are at right angles.

An approximate position at which a given crystal is at extinction may be recognized at once on rotation of the stage. It is not always easy to determine the exact position of extinction, since the crystal often appears to be dark through a rotation of several degrees; that is, the eye is not sensitive to the difference between no amplitude and a very small amplitude of vibration or intensity of light. Several methods have been devised to permit more accurate determination of the position of extinction. The methods of special importance are described herewith.

1. *Parallel polarized light.*—The ordinary method of observing the position of maximum darkness without accessory apparatus is sufficiently accurate for many purposes.

For this method and all others, it is necessary that the microscope be in accurate adjustment in order to secure correct results. The nicols must be accurately crossed, and (except when convergent light is used) the light must be as nearly parallel as it is possible to make it. To test the angle between the vibration planes of the nicols, remove all the lenses, ocular, objective, and condenser, from the microscope, and point it directly at the sun, the rays from which are parallel and so intense that the light passing through the nicols on account of a rotation of less than 1′ from the position of total extinction is readily visible. If either nicol has inclined end-surfaces complete extinction is impossible, because the inclined incidence causes a slight rotation of the plane of polarization. In such a case the test can be made more satisfactorily if the microscope has substage and upper diaphragms and they are closed. To obtain parallel light take the light from the open sky (or from a cloud) and remove the condenser.

With any method of determining the extinction position, the probable error of a single measurement may be reduced to any desired limit by sufficiently increasing the number of measurements and taking the average. It is also desirable to measure the position when rotating the stage clockwise, and again when rotating it counter-clockwise.

2. *Sensitive tint plate.*—A plate of gypsum (or other colorless mineral) cut to such a thickness as to produce a violet interference color (at the upper limit of the first order) between crossed nicols, is called a sensitive tint plate, because the eye is especially sensitive to slight changes of tint in this part of the color scale. It is usually mounted between narrow glass plates and marked "sensitive tint," "red 1st order," or "gypsum"; the arrow at one end indicates the direction of vibration of the slow ray in the plate. The plate should be used in most cases with the arrow in a position at 45° with the vibration planes of the nicols. It produces no effect when the arrow marking a plane of vibration in the plate is parallel with either nicol. It is inserted in a slot or other opening in the tube of the microscope, between the objective and the analyzer. When a crystal (or grain) not surrounded by other crystals occupies part of the field of the microscope, and is rotated exactly to the extinction position, it has no effect on the light, and the two nicols cause darkness. If the sensitive tint plate is interposed between the nicols, the whole field is colored in violet. If the stage is rotated slightly the crystal is no longer at extinction, and it changes the planes of vibration of the transmitted light, and causes a slight change in the color of that part of the field occupied by the crystal. Therefore, when there is no difference in color between that part of the field unoccupied and that part occupied by the crystal, the latter is at extinction.

3. *Bertrand ocular.*—It is necessary that part of the field of view be unoccupied, in order that the sensitive tint plate may be used satisfactorily. Furthermore, this plate is not well adapted to use with colored substances, nor with those which produce interference colors above the first order. The device of Bertrand is more complicated, but also more useful. It consists of four plates of quartz cut parallel with the base, two cut from right-handed quartz alternating with two from left-handed quartz. All the plates serve to produce circular polarization and to rotate the plane of polarization, the right-handed plates rotating the plane to the right (clockwise) and the others rotating it to the left. They are shaped as quadrants and placed in a special ocular, in which their rectangular edges correspond to cross hairs. This ocular must be used between crossed nicols; therefore, a

nicol must be superposed above the ocular, and the ordinary analyzer removed. When the nicols are exactly crossed the four quadrants are of the same pale greenish-blue color. If a thin section or grain of an anisotropic crystal is put on the stage in the focus of the microscope, not at the extinction position, the quadrants are differently colored, opposite quadrants being of the same tint, as in Fig. 155. When the stage is rotated, the quadrants become alike in color at the exact position of extinction. The vibration planes of the crystal then coincide with the principal planes of the nicols.

4. *Wright's biquartz wedge.*—There are several other devices sometimes used to determine accurately the extinction position; the most important of these is the biquartz wedge plate of F. E. Wright;[3] in this instrument two plates of quartz cut normal to the axis and of proper thickness, one right-handed and the other left-handed, are combined with two wedges of quartz selected to rotate the plane of polarization in the reverse direction, as shown in Fig. 156. The effect of this combination is to produce zero rotation in each half wedge, where the plate and wedge have the same thickness. It is used at the focal plane of the ocular, which must be cut so as to permit its insertion; a nicol must be used above the ocular, as with the Bertrand plate. The biquartz wedge divides the field into two halves, which are equally illuminated if no crystal is in the path of light, or if a crystal in the field on the stage is at extinction. If the crystal is turned even a very small angle from extinction, the intensity of illumination in the two parts of the field is rendered unequal.

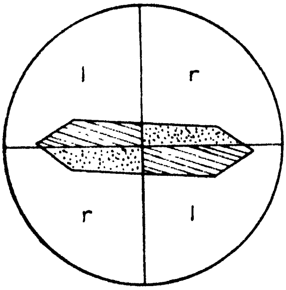

FIG. 155.—Bertrand ocular.

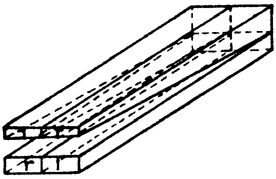

FIG. 156.—Wright biquartz wedge.

Extinction angles.—The angles between extinction positions and various crystallographic directions are called angles of extinction, or extinction angles. It is only necessary to measure from one extinction position to any given crystallographic direction, since extinction positions are always 90° apart. Usually the angle measured is that between a cleavage, crystal boundary, or twinning plane and the nearest extinction position. But in some cases the extinction angle is measured from a crystal plane to the plane of vibration of the fast (or the slow) ray.

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[3] *Am. Jour. Sci.*, XXVI, 1908, p. 377.

Optic sign of uniaxial crystals.—In uniaxial crystals the optic axis is parallel with the vertical crystallographic axis, *c*; the ordinary ray always vibrates at right angles to the optic axis; and the extraordinary ray vibrates in the principal section, which includes the incident ray and the vertical axis; when the light is traveling normal to the optic axis, the *E* ray vibrates parallel thereto. In certain substances the ordinary ray travels faster than the extraordinary ray; such substances are said to be positive or +; in this case the (*O*) ray vibrating normal to the principal section has greater velocity than the (*E*) ray vibrating in that plane. It is true for all substances that the greater the velocity the less the refraction and the smaller the index of refraction. Therefore, in positive crystals ω is less than ϵ, the index of *E* ray is N_g, and that of the *O* ray is N_p. In other substances the extraordinary ray travels faster than the ordinary, and these substances are said to be negative or −; in this case the ray vibrating in the principal section has greater velocity than the ray vibrating normal thereto; also, in negative crystals ω is greater than ϵ, the index of the *E* ray is N_p, and that of the *O* ray is N_g, while in positive crystals the index of the *E* ray is N_g, and that of the *O* ray is N_p.

There are various ways to determine whether a uniaxial crystal is positive or negative, that is, to determine its optic sign. One method is to make accurate measurements of ω and ϵ, as described later. Other methods involve the use of convergent light and " interference figures." Finally, there are methods by which the velocity of the ray vibrating parallel with the vertical axis is compared, in parallel polarized light, with the velocity of the ray vibrating normal thereto. This can be done only in case the position of the vertical crystal axis can be recognized or determined in some way, usually by means of the crystal outline. It is only necessary to find the vertical axis, and then determine, by means of superposing a plate, whether the ray vibrating parallel with this axis is the fast ray or the slow ray. In the latter case the substance is positive; in the former case it is negative.

To determine the relative velocity of the ray vibrating parallel with the vertical axis, which is the *E* ray for the crystal, any one of the methods already described may be used. If the crystal gives an interference color lower than white of the first order, the sensitive tint plate should be used; if the color is higher, but below the fourth order, the mica plate is preferable, if the color is still higher, the quartz wedge is commonly employed. The crystal should be turned 45° from extinction and the proper plate superposed with the arrow marking the plane of vibration of its slow ray also at 45° from the planes of the nicols. If the interference color rises, the arrow gives the direction of vibration of the slow ray in the crystal; if the color falls, the arrow is parallel with the direction of vibration of the fast ray in the crystal. In Fig. 157, a uniaxial crystal whose vertical axis is parallel with the elongation is shown in two positions, producing a red interference color between crossed nicols. If a mica plate is superposed the interference color rises to blue when the arrow of the plate is parallel with the vertical axis, and falls to yellow when the two are at right angles; therefore, the crystal is positive. In Fig. 158 a uniaxial crystal producing a dark gray interference color is shown in two positions. When the gypsum sensitive tint plate is superposed, the color changes to blue in one position and red in the other, and it might be inferred that the color had risen (from gray) in both cases. But the red is lower than the sensitive tint (with which the new color may better be compared in using this plate) and is produced by the action of the plate in lowering the interference color of the crystal to darkness and then raising it to red. In other words, the red color is produced by the addition of a plus and a minus quantity, while the blue color is produced by the

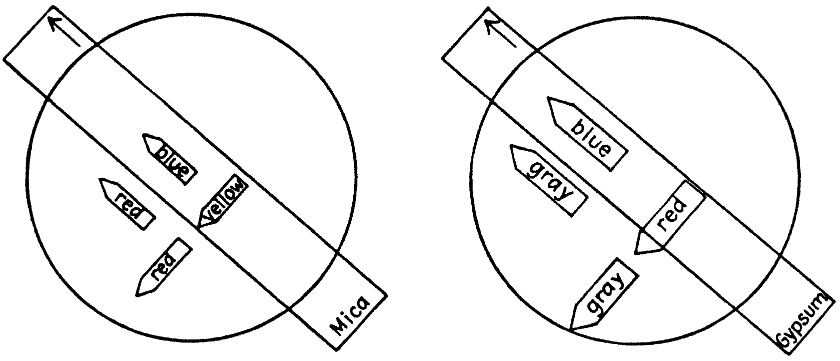

FIG. 157. FIG. 158.

FIGS. 157, 158.—Uniaxial positive crystals with superposed plates.

addition of two plus quantities. Since the color rises when the arrow is parallel with the vertical axis, the slow ray vibrates in that direction and the crystal is positive.

Occasionally the superposition of a plate causes changes in color such that it is not easy to decide whether the change is to a higher color or to a lower color; thus, the change when a mica plate is used may be from green of the second order to red, when the slow ray of the plate is parallel with the elongation, and also when they are at right angles. One of these red colors is red of the first order and the other is red of the second order, but it may be very difficult to determine which one belongs to either order. In some cases it is possible to solve the difficulty by compensating one of the red colors by using the quartz wedge. In some instances it is possible to determine the order of one of the red colors by observing a beveled edge. If any part of the crystal section, acting alone, produces an interference color other than green (because of varying thickness) a test of that part may give results which are easily understood. Again, a sensitive tint plate or a quartz wedge may be used in place of the mica plate and the results may be satisfactory. Finally, if the crystal section has a beveled edge, the direction of motion of the interference colors on that edge may be used to determine whether the main surface color is rising or falling. This is illustrated in Fig. 159, in which a long, smooth bevel is represented as producing colors from gray to red of the second order. Now, if a mica plate (or other plate) be superposed over this so that the main surface color falls, it is evident that the red surface color has been replaced by one of the colors formerly on the beveled edge. Therefore, when a given color, for example, white, moves up a beveled edge, the main surface color has fallen in the Newton color scale; and when a given color moves down on a beveled edge, the main surface color has risen.

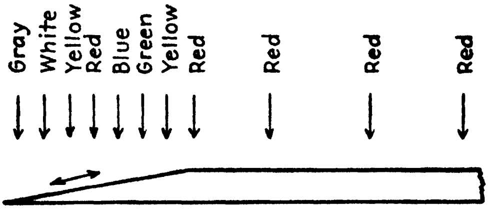

FIG. 159.—Movement of interference colors on a beveled edge.

Accurate measurements of the indices of refraction by the single or double variation method in immersion liquids give important information regarding the optic properties of crystals. For example, if a crystal has exactly the same index of refraction in any position of the rotating stage it is dark between crossed nicols and it is either isotropic and isometric,[4] or it is lying so that light passes through it parallel with an optic axis. It is easy to distinguish between an isotropic crystal and one lying normal to an optic axis, if the crystal can be turned about half-way over on the glass slide so that the light will no longer pass through it in the same direction, since, after such a turning, an isotropic crystal will still be dark in all positions of rotation of the stage, while any other crystal will produce double refraction. If a crystal is lamellar so that it cannot be turned on the glass slide that fact suggests that it is not isometric; the question can be settled by examining the crystal in convergent light (produced by a condenser) under a high-power objective; then, by removing the ocular or using a Bertrand lens an " interference figure " can be seen if the crystal is not isometric, while no figure is produced if it is isometric.

Next, if the crystal is uniaxial, and therefore tetragonal or hexagonal, any grain or particle which remains dark (or very nearly so) on rotation of the stage is lying with its optic and vertical axis, exactly (or nearly) in the axis of the microscope. The index of refraction given by such a grain is necessarily that for the ordinary ray which is designated as ω or N_o. After measuring the index of such a grain accurately it is only necessary to turn to a fragment of the same crystal lying so that it produces the highest interference color, and measure its index of refraction in each position of extinction. If the crystal is uniaxial, one of these indices will be exactly equal to the index given by the grain which remained dark on rotation, and this will be the index for the ordinary ray, ω or N_o. The other index will be the index for the extraordinary ray, designated ϵ or N_e. If N_e is greater than N_o, the crystal is optically positive or +; if N_e is less than N_o, the crystal is optically negative or −. If neither index of refraction obtained from the fragment showing the highest interference color is the same as the index given by the grain showing the lowest interference color (dark between crossed nicols while rotating the stage) then, assuming that only one kind of crystal is present, the crystal is not uniaxial, but must be biaxial.

DIRECTIONS FOR LABORATORY WORK

Newton's color scale.—Study the effect of the quartz wedge between crossed nicols on monochromatic light. (By burning table salt in a Bunsen burner flame, an intense yellow light may be obtained. Nearly monochromatic red or blue light may be obtained from ordinary light by filtering it through very deeply colored red or blue glass.) Then study the effect of the wedge on white light. Color the lower part of Fig. 149 as accurately as you can, making each color pass gradually into the next one. Use the colors produced by the wedge in white light as a guide, and compare the result with Michel Lévy's table of birefringence. Make a tracing of Fig. 150 and study the effect on each color when *O* of the tracing is over 1, 2, 3, etc., of the drawing.

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[4] An unknown grain may be isotropic because it is amorphous; in that case it is not a crystal nor a part of a crystal.

Determination of relative velocities.—To determine the relative velocities of the two rays transmitted by any crystal section not at extinction, turn the section 45° from extinction, or simply turn it to the position of maximum illumination, since accurate orientation is unnecessary. Note the interference color produced and the order to which it belongs. Superpose a mica plate, sensitive tint plate, or quartz wedge, with its vibration planes bisecting the angles between the nicols and therefore parallel with the vibration planes of the mineral section. Note the interference color now produced, and determine the order to which it belongs. If the interference color has risen, the slow ray in the crystal has passed through the superposed plate as the slow ray, and its direction of vibration is shown by the arrow on the plate. Note that the mica plate makes a change of interference color amounting to about one and a half of the major divisions on the table of Michel Lévy, while the sensitive tint plate moves the interference color about five and a half of the major divisions, or just one order; the quartz wedge produces a change the amount of which depends upon the thickness of the part of the wedge in use at any given position. Use these plates in determining the relative velocities of transmitted rays in anhedra of quartz, of muscovite, and of augite.

Determination of sign of elongation.—The sign of elongation of uniaxial crystals is + in those crystals in which the slow ray is parallel with the axis of elongation and − in those in which the fast ray occupies this position. Since the elongation of uniaxial crystals is usually parallel with the vertical axis, the sign of elongation of such crystals is usually the same as the optic sign of the crystal. If the elongation is parallel with the basal pinacoid, the sign of elongation is the reverse of the sign of the crystal. Determine the sign of elongation of H_2KPO_4 and $Ca_5F(PO_4)_3$.

Determine the extinction position in quartz by each method for which you have the necessary equipment. To test the relative accuracy of the various methods, take the average of several readings of the position as determined by each. Try the methods in the following order: First: Simple contrast of dark and light between crossed nicols in parallel polarized light. Find the position of maximum darkness. Second: With the sensitive tint plate find the position at which the quartz is colored exactly like the color produced by the plate alone. Third: With a Bertrand ocular remove the upper nicol and replace it by a nicol placed above the ocular. See that this nicol is exactly crossed with the lower nicol so as to cut off all light when no crystal intervenes. When the Bertrand ocular is in position and the nicols are crossed, the quadrants are all colored alike in a pale greenish-blue tint. Find the position at which the quartz section does not modify the equality of color of these quadrants. Fourth: With Wright biquartz wedge plate use a superposed nicol, as with the Bertrand ocular. See that the nicols are crossed and find the position at which the intensity of illumination in the two parts of the wedge is equal.

Determine the extinction angle in asbestus and gypsum fibers. The extinction angle is the angle between the extinction position and some crystallographic direction, in this case, the axis of the fibers. Turn the stage till the fibers are parallel to one of the cross hairs. The angle from this position to the nearest extinction position is the extinction angle; take the average of several readings of this angle. In asbestus the angle is very near zero degrees; in gypsum it is large.

Determination of optic sign.—Those uniaxial crystals are positive in which the vertical (and optic) axis is the direction of vibration of the slow ray, and those are negative in which it is the direction of vibration of the fast ray. Thus, the sign of the crystal can be determined by the methods giving the relative velocities of transmitted rays whenever the direction of the vertical crystal axis can be determined in any way, as, for example, by a study of the crystal form or the cleavage. Use, first sections of known orientation and determine the sign of quartz and apatite from vertical sections. Then determine the sign of tourmaline or apatite in rock sections.

CHAPTER VI

OPTIC PROPERTIES OF BIAXIAL CRYSTALS

As previously stated, isometric crystals are isoaxial; tetragonal and hexagonal crystals are uniaxial, and all other crystals (orthorhombic, monoclinic, and triclinic) are biaxial; in these there are two directions parallel to which all the light travels with the same velocity.

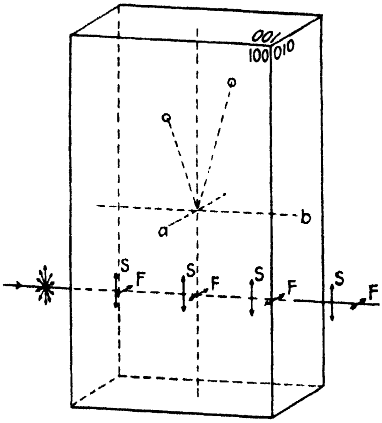

FIG. 160.—Effects of sulphur on light incident at right angles on any pinacoid.

Experimental double refraction in biaxial crystals.—The optic axis of a uniaxial crystal is parallel with the vertical axis, and all light of normal incidence passes through a basal plate with the same velocity and without polarization or refraction. In general, in biaxial crystals, neither optic axis is parallel with the vertical axis, and light of normal incidence on a basal plate is divided into two parts or rays traveling at unequal velocities and completely polarized in planes at right angles to each other. If the crystal is orthorhombic, like sulphur, neither ray is refracted at the surface of a basal section; both are "ordinary" rays in the sense of obeying the ordinary law of refraction. If such a section be placed over a small particle, two images of the particle are produced at unequal distances, directly above the object. In order to see these images separately it is necessary to use polarized light. A section of sulphur parallel to either the macro- or brachypinacoid produces exactly the same effects. All pinacoidal sections of an orthorhombic crystal act on light of normal incidence in the same way as vertical sections of uniaxial crystals; that is, two rays are produced which obey the ordinary law of refraction at the surfaces, but travel at unequal rates and vibrate in planes at right angles to each other, as in Fig. 160. The velocity of light in a given substance is inversely proportional to its indices of refraction; by measuring the indices of refraction of sulphur for each pinacoidal plate, the following results may be obtained:

INDICES OF REFRACTION OF SULPHUR

From Plate Parallel to	For Ray Vibrating Parallel to the Crystal Axis		
	a	*b*	*c*
Basal pinacoid (001)	1.95	2.04	
Macropinacoid (100)	. . .	2.04	2.24
Brachypinacoid (010)	1.95	. . .	2.24

It is evident from this table, not only that the indices are different for two rays of light traveling in the same direction, but vibrating in different directions, but also that the indices are the same for rays traveling in different directions, but vibrating in the same direction. The direction of vibration, and not the direction of transmission, determines the index of refraction.

If the indices of refraction are then measured in several plates, all of which are parallel to the vertical axis, *c*, but make various angles with *a* and *b*, it is found that in each plate the crystal of sulphur has the index, 2.24, for light vibrating parallel to *c*, and an index varying between 1.95 and 2.04 for light vibrating at right angles to *c* and at varying angles to *a* and *b*; indeed the index of the crystal varies gradually from 1.95 to 2.04, as the angle between the plate and the axis *a*, and the consequent angle between the direction of vibration of this ray and the axis *a* varies between 0° to 90°. The two paths and the unequal velocity of light incident normally on a vertical surface of sulphur are illustrated in Figs. 161 and 162, in which the plane of incidence is at right angles to the vertical axis. The construction of these figures is similar to that of similar figures for uniaxial crystals. (Figs. 130–143.)

Light incident normally on any surface of sulphur, the surface being parallel to one and only one crystal axis, and not normal to an optic axis, is divided into two rays polarized at right angles and traveling at unequal velocities, one of which is refracted, like an " extraordinary " ray and the other not refracted, like an " ordinary " ray.

In all biaxial crystals, the direction of vibration of the fast ray, having the smallest index, is designated as the axis X, that of the slow ray, having the largest index, as the axis Z, and that of the ray of intermediate velocity and intermediate index as the axis Y. In general, the ray vibrating parallel to Y has an index which is not half way between the indices of the rays vibrating parallel to X and Z, but may be nearer to either. The axes, X, Y, and Z, are at right angles to each other in all biaxial crystals.

The relative velocities of the two rays traveling in all directions at right angles to *c* in sulphur are represented in Fig. 163, in which the light is supposed to originate at the center, and move outward in all directions in the plane of the paper. It is thus traveling at right angles to the vertical axis, which is assumed to be normal to the paper at the center of the figure. Of the two rays traveling parallel to *a*, the slow ray, vibrating parallel to Z (which is parallel to *c* in sulphur) reaches the point S at the same time that the intermediate ray, vibrating parallel to Y (which is parallel to *b* in sulphur), reaches the point I; at the same time, also, the fast ray traveling parallel to *b* and vibrating parallel to X (which is parallel to *a* in sulphur) arrives at the point F. The wave-front of the slow ray is a circle of radius inversely proportional to 2.24, since for all directions of propagation the vibration direction is the same; the wave-front of the other ray

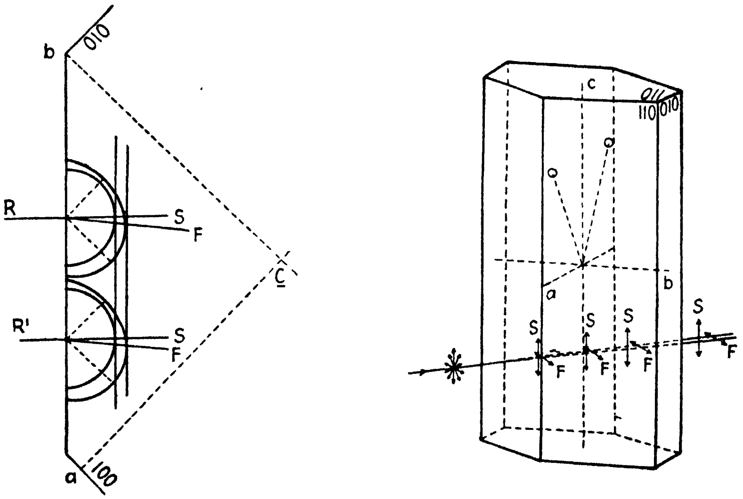

FIG. 161. FIG. 162.

FIGS. 161, 162.—Effects of sulphur on light incident at right angles on any prism face.

is an ellipse whose axes are inversely proportional to the indices, 2.04 and 1.95.

Measures of the indices of refraction of sulphur in plates parallel to *a* and making various angles with *b* and *c* establish the facts that the crystal has the index, 1.95, for light vibrating parallel to *a* in each plate, and an index varying gradually from 2.04 to 2.24 for light vibrating at right angles to *a*, and at gradually decreasing angles with *c*. The wave-fronts of the two rays propagated in all directions at right angles to the axis *a* in sulphur are represented in Fig. 164, in which the wave-front of the fast ray is a circle of radius inversely proportional to 1.95 wholly outside of the wave-front of the other ray which is an ellipse whose axes are inversely proportional to the indices 2.24 and 2.04.

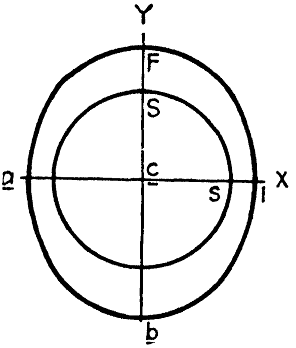

FIG. 163.—Wave-fronts normal to the vertical axis in sulphur, differences of velocity being exaggerated.

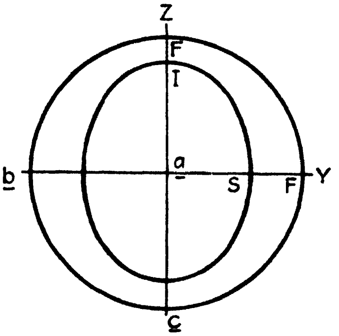

FIG. 164.—Wave-fronts normal to the axis *a* in sulphur, differences of velocity being exaggerated.

Measures of the indices of refraction of sulphur in plates parallel to *b* and making increasing angles with *a* show that the crystal has a constant index, namely 2.04, for light vibrating parallel to *b*, and an index varying gradually from 1.95 to 2.24 as the plate (and, therefore, the directions of vibration of the ray vibrating at right angles to *b*) makes increasing angles with the *a* axis. Consequently, there is a direction in this zone in which the varying index is exactly equal to the constant index, 2.04, and all the light accordingly travels with the same velocity. The wave-fronts of the two rays propagated in all directions normal to the axis *b* in sulphur are represented in Fig. 165, in which the wave-front of the intermediate ray vibrating parallel to *Y* (that is, *b* in sulphur) is a circle of radius inversely proportional to 2.04, which is cut at four points by the wave-front of the ray vibrating at right angles to the *Y*-axis.

A perspective drawing of the wave-fronts in sulphur is given in Fig. 166; in most biaxial crystals the relative velocities of the rays along the axes *X*, *Y*, and *Z* are much less unequal than shown in the figure, and the points, *S* and *S'*, may be nearer to *Z* or nearer to *X*; but the general form of the wave-fronts is the same in all. The relation in position between the axes *X*, *Y*, *Z*, and the crystal axes, *a*, *b*, *c*, is not fixed, and, in general, it is not the same as that shown in Fig. 166. It will be described later.

Measurements of the indices of refraction of sulphur, in any plate not parallel to a crystal axis, yield two values, both of which are greater than 1.95 and less than 2.24, one being greater and the other less than 2.04. The exact values vary gradually with the angles between the direction of vibration and the axes *X*, *Y*, and *Z*. Thus, the complete wave-fronts are continuous surfaces intersecting in only four points; three rectangular sections of the surfaces are shown in perspective in Fig. 166, and a wire model of the surfaces is shown in Fig. 167.

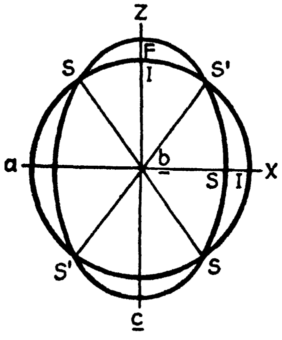

Fig. 165.—Wave-fronts normal to the axis *b* in sulphur, differences of velocity being exaggerated.

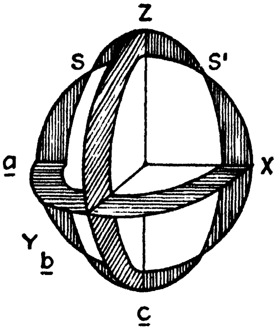

Fig. 166.—Wave-fronts in axial planes in sulphur, differences of velocity being exaggerated.

All plates of any orthorhombic crystal not parallel to any crystal axis (nor normal to either optic axis), and all plates of any biaxial crystal not parallel to any one of the axes *X*, *Y*, *Z* (nor normal to either optic axis), divide light incident at any angle (including that incident at 0°) into two rays, both of which are refracted at the surface in directions which do not lie in the plane of incidence. The two rays are polarized at right angles and travel at unequal rates. Since they do not lie in the plane of incidence, it is impossible to construct their paths by means of plane figures; a diagram on three coordinates must be used. It is unnecessary, for practical purposes, to determine the precise paths of the refracted rays, and the subject need not be pursued further. But it is worth while to emphasize the fact that, in the general case, both rays are refracted (out of the plane of incidence), even though the light is incident at right angles; therefore, in general, in biaxial crystals both rays are " extraordinary " in the sense of not obeying the ordinary law of refraction.

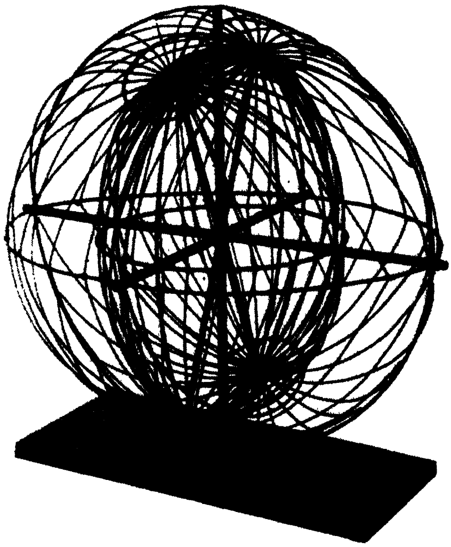

FIG. 167.—Model of wave-fronts of a biaxial crystal.

Triaxial ellipsoid.—In general, in biaxial crystals, for any direction of propagation there are two velocities; for any direction of vibration there is only one velocity and one index of refraction. As with uniaxial crystals, all the velocities and all the indices of refraction for every direction of propagation of vibration in biaxial crystals may be deduced from a single continuous surface, called an indicatrix, or index-ellipsoid. Such a surface is a triaxial ellipsoid, whose three symmetry axes are proportional to the three indices of refraction, namely, the greatest index, the least index, and the intermediate index of the crystal (the index for light vibrating at right angles to the directions of vibrations in the two preceding cases). The intermediate index of refraction is designated N_m, the subscript standing for mean, although the index is, in general, not a mean value of the other two, which are designated N_g and N_p, as in the uniaxial crystals. The general form of the triaxial ellipsoid of a biaxial crystal is shown in Fig. 168; this is not an ellipsoid of rotation, since all three axes are unequal. The three planes, *XY*, *XZ*, and *YZ*, are planes of symmetry of the form, and there are no other planes of symmetry. All sections of the form passing through the center are elliptical; in two positions (*YS* and *YS'*) the ellipses have their diameters equal and are circles. The two circular sections include the intermediate axis *Y* and are normal to the plane *XZ*. They must be equally inclined to *Z* (and also to *X*) since, beginning with the section *YZ*, which has its long axis in the plane *XZ*, and rotating the section to the right, a position must be found before reaching the position *X Y* in which the axis of the section in the plane *XZ* is equal to *Y*, inasmuch as this axis changes gradually from a length, *Z*, greater than *Y* to a length, *X*, less than *Y*; also, beginning with the same section and rotating to the left, another circular section must be found at the same angular distance from *Z*, since the curves on either side of *Z* are alike.

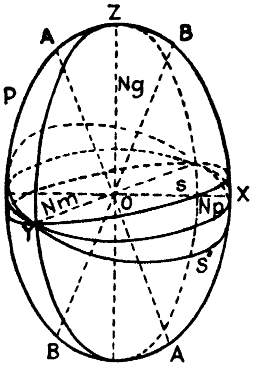

FIG. 168.—Triaxial ellipsoid.

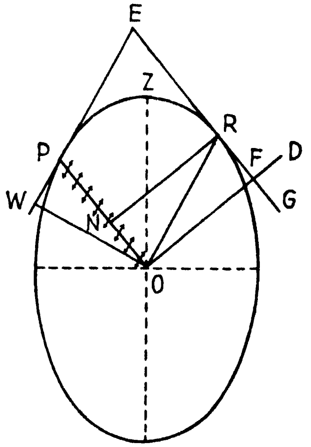

FIG. 169.—Derivation of index for a ray from the triaxial ellipsoid.

If light travels from the center, *O*, of the ellipsoid, in any direction in the plane *XZO*, as to the point *P* (in Figs. 168 and 169), it consists, in general, of two rays vibrating at right angles to each other and normal to the direction of propagation,[1] *OP*. If the point *P* is in one of the planes of symmetry, *XY*, *XZ*, or *YZ*, one direction of vibration is along that axis which is normal to the given plane of symmetry. In the case of the light traveling along *OP*, one part vibrates in the direction *OY* (suggested by the dots along *OP*) and its velocity is represented by $1/OY$, while the index of the crystal for this ray is represented by *OY*, or N_m. The other part, or ray, vibrates in the direction *OR*, normal to *OW* (*OW* being a wave-normal of the ray *OP*) and *OY*; its velocity is represented not by $1/OR$, but by $1/RN$, *N* being determined by dropping a perpendicular from *R* upon *OP*; the index of the crystal for this ray is represented by *RN*, or its equal *OF*, if *OD* is parallel with *RN* and *F* is its intersection with *EG*, the tangent through *R*, which is parallel with *OP*. In all cases, the line which represents the index extends from the center to the tangent plane to which it is normal. The lines representing the indices terminate at the surface of the ellipsoid only when they coincide with *OX*, *OY*, or *OZ*, which are the only radii that meet their normal tangent planes at that surface. If the point *P* is not in one of the planes of symmetry, *XY*, *YZ*, or *XZ*, both lines representing the indices extend beyond the surface of the ellipsoid.

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[1] More accurately expressed, the vibration directions are believed to be at right angles to the wave-normal directions.

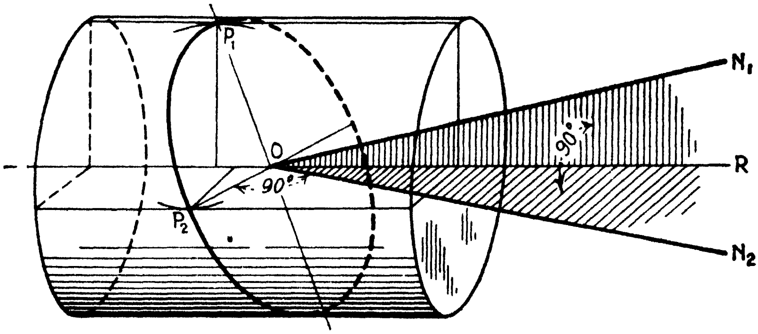

FIG. 170.—Derivation of index in the general case.

Finally, if light travels in any direction whatever, not in a plane of symmetry of the ellipsoid, it consists in general, of two rays whose wave-normals, vibration directions, velocities, and indices cannot be obtained from any two-dimension figure, but may be obtained from a three-dimension model as follows:

In Fig. 170 let *OR*[2] represent the direction of the rays. Construct a cylinder (of elliptical cross section) parallel to *OR* and tangent at all points of an ellipse (P_1P_2) to the indicatrix, and find the chief axes of its elliptical cross section; the half-lengths of these axes are the reciprocals of the velocities of the rays; the symmetry planes of the cylinder are the vibration planes of the rays. If P_1 and P_2 are the points of tangency of the tangent cylinder lying in these symmetry planes, OP_1 and OP_2 are the vibration directions of the rays. If

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[2] *OR* may be considered to be a ray from the center *O*, of the triaxial ellipsoid (Fig. 169) to an indefinite point, *R*.

ON_1 is normal to OP_1 in the plane P_1OR, and ON_2 normal to OP_2 in the plane P_2OR, then ON_1 and ON_2 are the wave-normals of the rays. If perpendiculars are dropped from P_1 and P_2 upon OR (produced), these lines are proportional to the indices of the crystal for the rays and are inversely proportional to their velocities.[3]

The directions of vibration of the light moving in a certain direction are always at right angles to the wave-normals and to each other; the traces of the positions of these directions in the plane normal to the ray are determined by the positions of the major and minor axes of the elliptical section of the triaxial ellipsoid cut through its center by the plane normal to the ray. These directions of vibration bisect the angles between the intersections of the plane normal to the ray and the two circular sections of the ellipsoid; they also bisect the angles between the intersections of the plane normal to the ray and the two planes each containing the ray and one optic axis; or, again, they bisect the angles between the projections of the optic axes on the section, or plane of the microscope-stage.

Optic Axes.—The two directions normal to the circular sections of the triaxial ellipsoid are called the optic axes (primary) and are commonly denoted by the capital letters *A* and *B*. In orthorhombic crystals one optic axis is indistinguishable from the other, so far as its effects on light are concerned; in other biaxial crystals there is no necessary nor constant difference between them. Since all diameters of the circular section are equal, all light rays whose wave-normals are parallel to either optic axis travel at velocities whose components in the direction of their wave-normals are equal; the rays in one cone have all possible directions of vibration (parallel to all diameters of the circular section).

There is a very small angular difference[4] of position between the directions *AA* and *BB* of Fig. 168, and the directions *SS* and *S'S'* of Fig. 165; the former are distinguished as primary optic axes and the latter as secondary optic axes. The difference in position is 0° 12′ in orthoclase, 0° 15′ in barite, 0° 52′ in diopside, and is more than 2° only in crystals of large optic angle and very strong birefringence. For distinctness, this difference is exaggerated in Fig. 171, in which *OP* is the primary optic axis normal to the circular section of the triaxial ellipsoid at its center, and *OR* is the secondary optic axis, whose position is established as in Fig. 165. Neither the primary nor the secondary optic axis is an axis of no double refraction, like the optic axis of a uniaxial mineral, but the wave-normal of light traveling along the primary axis suffers no change of direction. The two axes are indistinguishable in common substances by ordinary methods. The plane *bb′* in Fig. 171 is tangent to the surface *II* at *P*, and also to the surface *FC* at *D*; furthermore, it is tangent to these surfaces along a continuous circular line of which *P* and *D* are the extremities of the diameter marking the intersection of the optic plane; the plane of the circle is normal to the plane of the paper.

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[3] For a more complete discussion and demonstration see L. Fletcher: The Optical Indicatrix, London, 1892, and F. Pockels: Lehrbuch der Kristalloptik, Leipzig, 1906, pp. 48–55.

[4] If $AOB = 2V$ and $SbS' = 2W$, then $\tan V = \frac{N_g}{N_p} \tan W$ for a positive crystal.

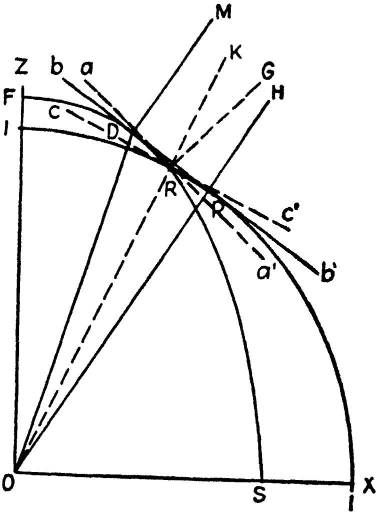

FIG. 171.—Interior and exterior conical refraction.

Optic plane, optic normal, and bisectrices.—The optic axes lie in the plane of the greatest and least axes of the triaxial ellipsoid, which is called the plane of the optic axes, or, simply, the optic plane. The axis *Y*, being at right angles to the optic plane, is known as the optic normal. The axes *X* and *Z* bisect the angles between the optic axes, and are therefore called the bisectrices; the one which bisects the smaller angle between the optic axes is known as the acute bisectrix, and the other is designated the obtuse bisectrix. The acute angle between the optic axes is called the optic angle, and is denoted by $2V$.

Crystals in which *Z* is the acute bisectrix are said to be *positive*, for, if the angle between the optic axes be supposed to diminish to 0° (the limiting case), the two optic axes coincide, and the triaxial ellipsoid becomes an ellipsoid of rotation with its long axis coincident with the optic axis, which is the condition in a positive uniaxial crystal.

Crystals in which *X* is the acute bisectrix are said to be *negative*, for, if the angle between the optic axes diminishes to its limit, the triaxial ellipsoid becomes an ellipsoid of rotation with its short axis coincident with the optic axis, which is the condition in negative uniaxial crystals.

The angle between the optic axes is closely related to the relative values of N_g, N_m, and N_p; indeed, if this angle is represented by $2V$, the exact relation between it and the indices of refraction is given by the equation:

$$\tan V = \sqrt{\frac{I/N_p^2 - I/N_m^2}{I/N_m^2 - I/N_g^2}}$$

The relation may be stated more simply as follows, if a close approximation is sufficient:

Positive Crystals

$$\tan V = \sqrt{\frac{N_m - N_p}{N_g - N_m}}$$

Negative Crystals

$$\tan V = \sqrt{\frac{N_g - N_m}{N_m - N_p}}$$

Also,

Positive Crystals

$$\sin^2 V = \frac{N_m - N_p}{N_g - N_p}$$

$$\cos^2 V = \frac{N_g - N_m}{N_g - N_p}$$

Negative Crystals

$$\sin^2 V = \frac{N_g - N_p}{N_m - N_p}$$

$$\cos^2 V = \frac{N_g - N_p}{N_g - N_m}.$$

Optic orientation.—There is a remarkably close relation between the symmetry of crystals and their optical properties. Isometric crystals, which have three equal crystal axes that are commonly also principal axes of symmetry, have a wave-front whose axes are all equal. Tetragonal and hexagonal crystals have one principal axis of symmetry, and equal crystal axes at right angles to it; optically, the principal axis of symmetry is an optic axis and all the axes of the wave front at right angles to it are equal. No other crystals have a principal axis of symmetry (that is, one in which like planes of symmetry meet), and no other crystals have only one optic axis. Orthorhombic crystals have three rectangular axes of binary symmetry coincident with the three unequal crystal axes, and the three unequal ellipsoidal axes are parallel with them; in orthorhombic crystals of various kinds, any one of the ellipsoidal axes may coincide with any one of the crystal axes. Monoclinic crystals have one axis of binary symmetry (the crystal axis, *b*) with which one axis of the triaxial ellipsoid coincides in all cases. There being no symmetry axes to fix their position, the other two ellipsoidal axes (always at right angles to each other and to the first ellipsoidal axis) have positions in the plane of symmetry containing the crystal axes *a* and *c*, which vary with variations of chemical composition, and also, in a single crystal, with the wave-length of the light. Finally, triclinic crystals have no axes and no planes of symmetry; in them the axes of the triaxial ellipsoid may occupy any position whatever, depending upon the composition of the crystal and the kind of light used, but always being at right angles to each other, and fixed in position for any kind of monochromatic light for all crystals of exactly the same composition of a given species.

Absorption and pleochroism.—All substances absorb more or less of the light which is reflected or refracted at their surfaces. In isometric crystals, the amount of absorption bears no relation to the crystal form; in uniaxial crystals it may vary with the direction of vibration of the light, and in cases of variation the absorption is a maximum or a minimum for light vibrating parallel to the optic axis, and a minimum or a maximum for light vibrating at right angles thereto. In biaxial crystals, the amount of absorption may vary similarly, and the variation may reach a maximum or a minimum for light vibrating parallel to any one of the three ellipsoidal axes. The facts in regard to absorption in biaxial crystals are not completely expressed without stating the absorption parallel to each of the ellipsoidal axes. Absorption formulas are commonly written in terms of these axes; thus, $X > Y > Z$ means that the crystal has the greatest absorption for light vibrating parallel to X and the least for that vibrating parallel to Z.

Crystals not only absorb various proportions of the total light as the direction of vibration changes; they also, in many cases, absorb unequally the various kinds (wave-lengths) of light. Therefore, the color of reflected or transmitted light may vary with the direction of vibration. In biaxial crystals, such selective absorption may result in three different colors for light vibrating parallel to the three ellipsoidal axes. A pleochroism formula is a brief expression of the color observed with light vibrating successively parallel to each of these axes. For example, $K_2Co(SO_4)_2 \cdot 6H_2O$ has the following pleochroism formula: X = violet red, Y = yellow, Z = yellowish pink.

DIRECTIONS FOR LABORATORY WORK

Make drawings similar to Figs. 161 and 162 showing the effects of sulphur on light incident at right angles on the face 011.

CHAPTER VII

BIAXIAL CRYSTALS IN PARALLEL POLARIZED LIGHT

Biaxial crystal plates between crossed nicols.—In general, biaxial crystals affect parallel polarized light in the same way as uniaxial crystals. Except at the extinction position, a ray of polarized light is divided at the surface of the crystal into two rays which vibrate in planes which are at right angles to each other and are inclined to the planes of the nicols. The two rays are both refracted, and are refracted unequally, if the incidence is inclined; the same is true if the incidence is normal, provided the plate is not normal to a plane of symmetry of the triaxial ellipsoid. On account of the differences of phase of the transmitted light, interference colors are produced just as with uniaxial crystals. When a biaxial crystal plate is rotated between crossed nicols, monochromatic light is extinguished when the vibration planes of the crystal coincide with the vibration planes of the nicols. In most biaxial crystals, white light is extinguished under the same conditions; in a few the vibration planes of different colors are not coincident nor so close together that their separation produces no visible effect—in these crystals it is only possible to obtain extinction of one part of the spectrum at any given position.

Sections of uniaxial crystals normal to the optic axis cut off all the light between crossed nicols, provided the rays are strictly parallel and strike the sections at right angles. Under the same conditions plates of biaxial crystals normal to an optic axis do not cut off all the light, the amount passing through depending upon the birefringence, the dispersion, etc. This difference is due to several facts; the optic axes of biaxial crystals are not precisely the same in position for different parts of the spectrum; therefore no single section can be exactly normal to the optic axis for all colors; also, the effects of the primary and secondary optic axes are commonly blended, so that refraction occurs at each surface of the place (interior and exterior conical refraction), and the vibration·directions of part of the light are so shifted as to allow a small portion to pass through the analyzer.

Extinction angles.—Isoaxial crystals are extinguished in all positions between crossed nicols and therefore have no extinction angles. Uniaxial crystals have extinction which is parallel to basal or prismatic faces or cleavages in all sections; the extinction is, in general, not parallel to rhombohedral faces or cleavages. In common biaxial crystals, the most prominent faces and cleavages are either pinacoidal or prismatic. The extinction directions in such crystals bisect the angles between the projections of the optic axes on the section, or on the plane of the microscope-stage. In sections parallel to the vertical axis, extinction is parallel to pinacoidal or prismatic cleavage in orthorhombic crystals; it is inclined to such directions, except in orthopinacoidal sections, in monoclinic crystals, and is inclined to such directions in all vertical sections in triclinic crystals.[1]

In cross sections (that is, those normal to the vertical axis) extinction is parallel to pinacoidal cleavage in orthorhombic and monoclinic crystals, and inclined in triclinic minerals; in the same sections, extinction bisects the angles between prismatic cleavages (and is therefore called symmetrical) in orthorhombic and monoclinic crystals, and is inclined in triclinic.

In sections parallel to the side pinacoid (010), extinction is parallel to pinacoidal or prismatic cleavages in orthorhombic crystals, and inclined to those directions in monoclinic and triclinic crystals.

In general, extinction, measured on pinacoidal or prismatic cleavages or faces, is parallel or symmetrical in all sections parallel to one (or two) crystal axes in orthorhombic crystals; it is parallel or symmetrical in all sections parallel to the ortho-axis, *b*, and inclined in all other sections in monoclinic crystals; and it is inclined in all sections parallel to a crystal axis in triclinic crystals.

Extinction angles may be made more useful when they are expressed in terms of the relations between definite vibration planes and definite crystal directions. For example, it is true that the maximum extinction angle in the vertical zone in some types of hornblende is 20°, but it is much better to express this as the angle between the vibration direction of the slow ray (Z) and the direction of the vertical axis (c), thus, $Z \wedge c = 20°$. This makes the statement more exact, and thus doubles the possible range of extinction angles which can be measured. For instance, if the extinction angle in the vertical zone of augite is measured, it will be found to have a maximum value of 40° in one type. In this case the measure made is merely to the extinction position nearest the direction of the cleavage which marks the vertical axis. But if the measure is always made from the cleavage to the vibration direction of the slow ray, *Z*, it is clear that 45° is no longer the greatest possible angle—this is now 90°. Therefore, augite, whose maximum extinction angle in the vertical zone is 40°, may be distinguished from another type whose maximum extinction angle is 50°.

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[1] Parallel extinction is not impossible in triclinic crystals, but in them it would be merely a result of chance.

The measurement of extinction angles, thus, to a specified vibration direction is useful if the orientation of the crystal plate is known. The orientation may be only imperfectly known, as illustrated by the measurements just cited *in the vertical zone*; in such a case, it is necessary to make several measures in differently oriented grains or anhedra (in the zone) and assume that the largest angle found is the true maximum of the zone. This assumption is justified as an approximation, because it is usually true that a large part of the zone gives an angle varying only a little from the maximum. This is one of the methods used in determining plagioclase feldspars, the zone most frequently used being that normal to the twinning plane (010), which shows equal extinction angles in the two parts of the twin.

Again, the orientation may be definitely known with respect to crystal directions, as illustrated when extinction angles are measured in cleavage fragments from a known cleavage direction. This is another method used in studying feldspars, the extinction angles of which are useful in flakes from either cleavage.

Finally, the orientation may be definitely known with respect to optical directions, as is the case when extinction angles are measured in sections normal to optic axes, bisectrices, or the optic normal. Since sections normal to optic axes are indistinguishable one from the other, and, moreover, are nearly at extinction in all positions, so that extinction positions cannot be accurately determined, these sections are rarely used for this purpose. The measurement of extinction angles in sections normal to bisectrices is a very useful method in the study of triclinic crystals, especially the plagioclase feldspars. In some monoclinic crystals the measurement of extinction angles normal to *Y* gives better and more definite results than a search for the maximum extinction angle in the vertical zone, because, in those monoclinic minerals in which *Y* is parallel with *b*, the extinction angle normal to *Y* is not necessarily the maximum angle of the vertical zone.

The position of the axes X, Y, and Z, in three minerals having Y parallel with b, is shown in Fig. 172. The position of X, Y, and Z in three substances having X parallel with b is shown in Fig. 173.

Sign of Elongation.—The elongation of biaxial crystals is, in most cases, parallel with the vertical axis; wollastonite is elongated parallel with the axis b; some crystals of feldspar are elongated parallel with the axis a. Many biaxial minerals, including kaolinite, pyrophyllite and barite are elongated or flattened parallel with the base (001); a few, like microcline, and gypsum are flattened parallel with the side pinacoid (010); and serpentine, monazite, chrysoberyl, etc., are flattened parallel with the front pinacoid (100)

As with uniaxial crystals, the sign of elongation is determined by the relation in position of the directions of vibration and the direction of elongation (or flattening). The sign of elongation is positive in case the direction of vibration of the slow (Z) ray is nearest to, or coincides with, the axis of elongation, and it is negative in case the fast (X) ray occupies this position. If the intermediate axis, Y, is nearest to, or coincides with, the axis of elongation, the sign of elongation is plus in some sections and minus in others, and the substance is said to have an elongation which is plus or minus (±). Thus, if an orthorhombic crystal is elongated parallel to Y and c, and if Z is parallel with a, the elongation is positive in a macropinacoidal section and negative in a brachypinacoidal section, since the ray vibrating parallel to Y travels faster than the Z ray, but more slowly than the X ray.

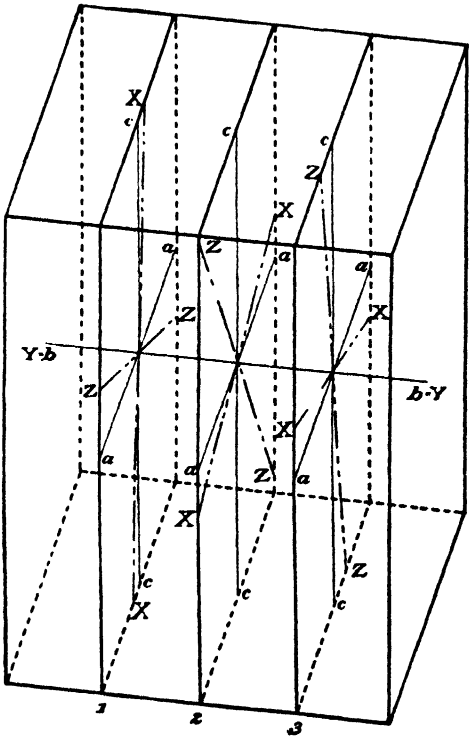


Fig. 172.—Position of the axes X, Y and Z in (1) epidote, (2) $CaMgSi_2O_6$, and (3) glaucophane.

In monoclinic and triclinic crystals in which, in general, no direction of vibration is parallel with the axis of elongation, the sign of elongation is determined by the relative velocity of that ray whose vibration direction is nearest the axis of elongation. Thus, all pyroxenes (except those varieties in which the optic plane is normal to 010) have positive elongation when the angle between *Z* and *c* is less than 45°, and negative elongation when it is greater than 45°.

In crystals which exhibit flattening (or elongation parallel to a plane), all sections except those parallel to the plane of flattening show

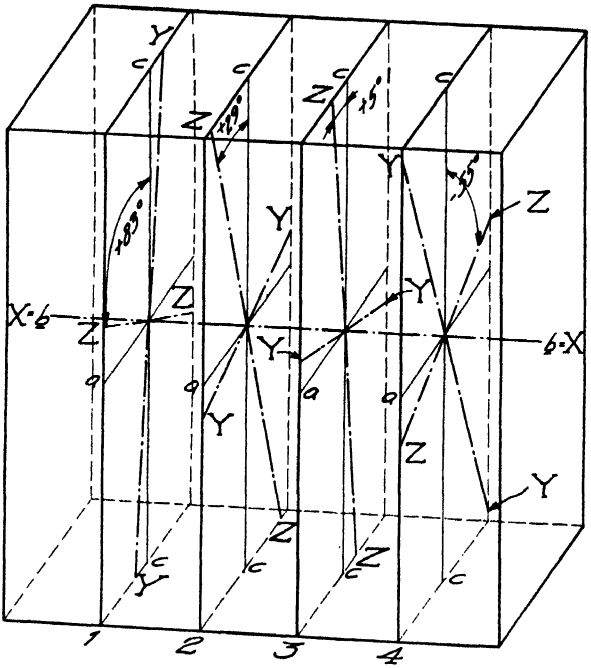


FIG. 173.—Position of the axes *X*, *Y* and *Z* in (1) $Ca_2B_6O_{11} \cdot 5H_2O$, (2) $Fe_3P_2O_8$, $8H_2O$, (3) monazite, and (4) $Na_2B_4O_7 \cdot 10H_2O$.

an apparent elongation whose direction is variable, depending upon the direction in which the section is cut. In such crystals the sign of elongation is determined by the relation in position of the vibration directions (axes of the triaxial ellipsoid) and the normal to the plane of flattening. The sign of elongation is positive in case *X* coincides with, or is nearest to, the normal to the plane of flattening, plus or minus (±) in case *Y* is so situated, and negative in case *Z* occupies this position. Thus, kaolinite and barite have positive elongation, since in them *X* is normal to the basal flattening.

DIRECTIONS FOR LABORATORY WORK

Interference colors.—Many sections of biaxial crystals (all sections of some biaxial crystals) produce, between crossed nicols, interference colors which are indistinguishable from those produced by uniaxial crystals; they are due to the same causes and dependent upon the same factors, namely, the birefringence of the substance, the direction in which the section is cut, and the thickness of the section. Sections parallel to both optic axes (and therefore parallel to the optic plane) produce the highest interference colors; those normal to an optic axis produce the lowest colors. Find sections normal to an optic axis of one or more biaxial crystals (for example, $BaSO_4$ or KNO_3) and describe the amount and kind of light transmitted by them between crossed nicols.

Some cyanides, including $Na_2Pt(CN)_4 \cdot 3H_2O$, have such strong dispersion of their vibration directions that in no position of rotation are the vibration planes for all parts of the spectrum parallel to the vibration planes of the nicols. Therefore, there is no position of complete extinction for sections of such substances, and, near the extinction position, abnormal interference colors are observed.

Extinction angles.—Oriented sections may be used to advantage in the preliminary study of extinction angles.

Test the following statements and record results:

Extinction is parallel to prismatic cleavages in all sections of the vertical zone in an orthorhombic substance, for example, orthorhombic $MgSiO_3$.

Extinction is symmetrical in all sections parallel to *a* or *b* and not parallel to *c*, in the same substance.

Extinction is inclined in all other sections of the same substance.

Extinction is parallel to pinacoidal cleavage in all sections parallel to any crystal axis in an orthorhombic crystal, for example, $CaSO_4$.

Extinction is inclined in all other sections of the same substance.

Extinction is parallel to prismatic cleavage in orthopinacoidal (100) sections of a monoclinic crystal, for example, $CaMgSi_2O_6$. In the same substance it is symmetrical in other sections parallel to *b*, and inclined in all other sections.

Extinction is parallel to pinacoidal cleavage in all sections parallel to *b* in a monoclinic crystal, for example, $KAlSi_3O_8$. It is inclined in all other sections of the same substance.

Extinction is inclined to prismatic cleavage in all sections of a triclinic crystal, for example, $BaCdCl_4 \cdot 4H_2O$.

Extinction is inclined to pinacoidal cleavage in all sections of a triclinic crystal, for example, $NaAlSi_3O_8$.

These facts may be used, not only to determine the crystal system and thereby gain a clue to the character of an unknown crystal, but they may be employed also to fix the orientation of sections of a known crystal.

Sign of elongation.—Determine from sections the sign of elongation of several biaxial crystals, for example, asbestus, gypsum, and $NaHCO_3$. Use the same methods employed with uniaxial crystals.

CHAPTER VIII

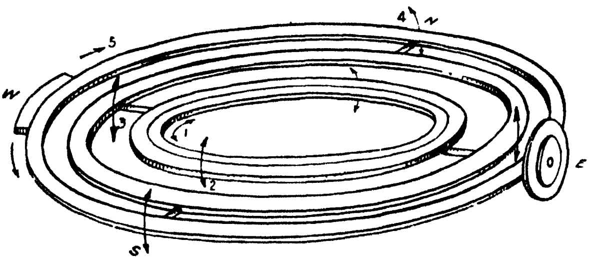
THE UNIVERSAL STAGE

By R. C. Emmons

Heretofore the discussion has dealt with thin sections and grains in random orientations in immersion media, from a study of which the student can frequently reach valuable conclusions. However, it is commonly necessary to search carefully for a grain of suitable orientation for a particular purpose and even then it is seldom that the orientation is exactly correct. In measuring refractive indices of anisotropic substances the accuracy desired depends on the purpose in mind. For a cursory study of indices, which aims merely at a confirmatory determination, a random grain is usually sufficient. When the unknown substance is one of several substances having approximately the same indices of refraction, greater accuracy is needed and this usually means, first, that the grain being studied must have a known critical orientation, one that will transmit rays with two critical indices, N_g and N_m or N_m and N_p or N_g and N_p for biaxial crystals or N_o and N_ϵ for uniaxial crystals. To secure a critical orientation by rotating grains on a microscope slide is most uncertain. To identify such orientations is not always easy, and, if accurate critical orientations are necessary, then mere manual rotation of grains on a slide is quite unsatisfactory, as it very seldom yields an accurately oriented grain.

The universal stage has for its main purpose the rotation of a mount to give any orientation desired within a rather wide range. By means of this rotation light is transmitted in such a way that the refractive indices for critical directions may be measured with considerable speed and accuracy. From these refractive indices the optic angle (2V) can be calculated and the optic sign determined. The optic angle and sign may also be determined readily by direct measurement on the universal stage. Reliable checks of the universal stage are thus obtained which reveal and usually locate errors, which may creep into determinative work, and at the same time these added critical data are made available. The procedure yields, too, the dispersion of the various rays in the same manner as brought out in the discussion of the double variation method. The calculations are facilitated by the graphs given in Plates I–IV, which relieve the operator of the necessity of complicated graphical construction.

The modified universal stage has six axes of rotation which, from the center out, are as follows: First, a *vertical inner stage axis* (see Fig. 174 and also Fig. 112, on page 48). This is used to turn the grain to extinction. Second, an *inner east-west horizontal axis.* This is used to tilt the grain after extinction is reached in order to bring the first optic symmetry plane into a position parallel with the E–W nicol. Third, a *north-south horizontal axis.* This is used to bring one of the critical vibration directions which lies in the first optic symmetry plane into a position parallel with the axis of the microscope.



1. Inner stage vertical axis rotation. 3 N.S. horizontal axis rotation.
2. Inner stage E.W. horizontal axis rotation.
4. Outer stage E.W. horizontal axis rotation.
5 Outer stage vertical axis rotation.

FIG. 174.—Movements of the improved universal stage.

It is also used to search the first optic symmetry plane for optic axes as shown in detail below. Fourth, an *outer east-west horizontal axis.* The graduation on this axis carries a vernier. It is used to search the second optic symmetry plane for optic axes and it is also used to measure the optic angle in either plane, if the optic plane is identified as one of them. Fifth, a *vertical outer-stage axis.* This is used to rotate the first optic symmetry plane into a north-south position in case it should be found to be the optic axial plane. This makes it possible to measure V or 2V on the vernier scale. Berek uses this rotation to measure the optic angle indirectly. Sixth, the microscope stage vertical axis, or, better still, as on some microscopes, the *axis of simultaneous rotation of both nicols.* This is used just before making the actual measurement of the optic angle. The nicols are rotated to the 45-degree position which gives the sharpest extinction when an optic axis is brought parallel to the axis of the microscope. The order in which these rotations are described is essentially the order in which they are used. For uniaxial crystals fewer axes of rotation are needed than for biaxial crystals.

Uniaxial crystals.—For any position of extinction of a uniaxial crystal the plane of vibration of one of the nicols includes the optic axis of the crystal. If then the crystal is rotated on an axis perpendicular to this plane, the optic axis must still remain in the plane—or, in other words, the crystal will remain at extinction. If, on the other hand, the crystal is rotated on a horizontal axis which lies in the plane to which the optic axis is parallel, then the crystal will depart from extinction unless the optic axis is either parallel or perpendicular to the rotation axis. For, otherwise, the optic axis is rotated out of a position of parallelism with one of the nicols.

In order to orient a uniaxial crystal, this line of reasoning may be reversed. Turn the crystal to extinction on the vertical inner stage axis. Rotate, first on one horizontal axis, then on the other perpendicular to it. On one of these rotations the crystal will remain at extinction. The optic axis lies in the plane that is perpendicular to this axis of rotation. There are two theoretical possibilities that the crystal will remain at extinction on both rotations—the optic axis is either horizontal or vertical, and, therefore, on either rotation it is parallel constantly with the vibration plane of a nicol. If the optic axis is horizontal, the crystal will show its maximum birefringence in the 45-degree position, and if vertical, it will show no birefringence in the 45-degree position.

The recommended procedure, then, is to select a grain of rather strong birefringence. Turn to extinction. Rotate on each of the two horizontal axes in turn and note on which rotation the crystal remains at extinction. Make this the E–W axis by a 90-degree rotation, if necessary, on the inner stage vertical axis. Then rotate slowly on the inner E–W axis in one direction until it is possible to rotate on the N–S axis without departing from extinction. If a crystal of relatively strong birefringence was selected, then only the position of maximum birefringence can be reached, that is, it is possible to make the optic axis horizontal, but probably not vertical. However, the vertical position is not needed except to test for a small optic angle. In the horizontal position both of the rays wanted are transmitted.

Biaxial Crystals.—The three dimensional wave-front model of biaxial crystals (the triaxial ellipsoid) has three mutually perpendicular planes of symmetry, illustrated in Fig. 175. The vibration directions of rays having indefinite directions of transmission are somewhat complicated. But, since rays whose refractive indices are of critical value vibrate within these symmetry planes and are also transmitted in directions which lie in these planes, attention may be confined to these directions within the crystal. It is to be remembered that light being transmitted in a given direction within a plane of symmetry is composed of two rays one of which vibrates in the same plane and the other in a direction normal to that plane, both vibration directions being perpendicular to the direction of light transmission. The aim then is to adjust the crystal until the axis of the microscope lies in at least one of the planes of symmetry of the triaxial ellipsoid. When this condition is fulfilled the line of intersection of the other two planes is perpendicular to the axis of the microscope. This line of intersection is always one vibration direction of the light transmitted and this ray has a critical refractive index. The other vibration direction lies in the plane of symmetry which includes the axis of the microscope; the refractive index of this ray is between the other two critical indices. A rotation in either direction on an axis perpendicular to this plane

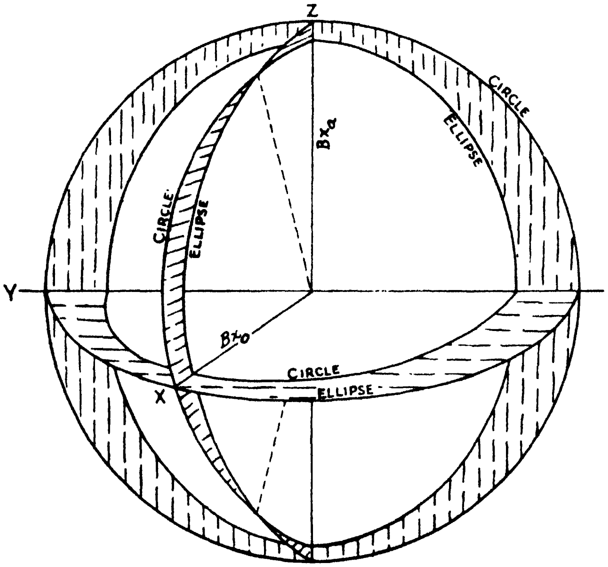


Fig. 175.—Symmetry planes of the triaxial ellipsoid in perspective.

causes the second ray to change in refractive index toward one or the other of the remaining two critical refractive indices. This principle is used when the full rotation cannot be made, to extrapolate and obtain the critical indices, either the third from the second and an intermediate reading, or the second and third from two intermediate readings.

Normally a crystal fragment or thin section of a crystal suitably mounted on the microscope stage is so oriented that the axis of the microscope lies diagonally in one of the indicatrix octants and not in one of the planes of symmetry. That is, the orientation of the selected grain is safely assumed to be such that X, Y, and Z are all inclined to the axis of the microscope and to the stage of the microscope. The first step in orienting the grain is to make one of the planes of symmetry of the triaxial ellipsoid in the crystal parallel to one of the planes of the nicols. To do this three rotations of the stage are needed. Using the vertical inner stage rotation turn the grain to a position of extinction. This position will suffice as a starting point without the next step, but the procedure is somewhat simplified if the next step is taken. Next rotate separately on each of two mutually perpendicular horizontal axes of rotation, and note on which axis the grain departs less from extinction. Then rotate 90 degrees, if necessary, on the vertical inner stage axis to make a rotation on the north-south axis depart less from extinction. Now the grain is so oriented that when all horizontal axes read zero the steepest optic symmetry plane strikes in a general east-west direction, and dips either north or south. The steeper the dip the less is the departure of the strike from a true east-west direction.

To make this symmetry plane parallel to the east-west nicol the procedure is as follows: Rotate a few degrees on the inner E–W horizontal axis in either direction. This causes the crystal to depart from extinction. Bring the crystal back to extinction by a small rotation on the inner stage vertical axis. Now if the first of these two rotations was made in the right direction, the crystal in its new position may be rotated on the N–S horizontal axis and the departure from extinction will be less than before. If the departure from extinction is greater than before, then this first rotation was in the wrong direction. In other words, it must be determined empirically whether the first optic symmetry plane is dipping north or south. Having decided in which direction to rotate the crystal on the inner stage E–W horizontal axis, then by successively rotating on this axis a few degrees returning the crystal to extinction by a rotation on the inner stage vertical axis, and testing by a rotation of the N–S horizontal axis, the first optic symmetry plane is made parallel to the E–W nicol. Parallelism is obtained when a rotation on the N–S axis does not disturb extinction. This operation is a " cut and try " procedure and is, therefore, the most difficult and unsatisfactory feature of the universal stage manipulation. However with a little practice it requires very little time. We have now made the first optic symmetry plane parallel to the E–W nicol. We may safely assume that the other two symmetry planes (which we know are striking true north and south) dip one east and one west. There is only a theoretical possibility that one is vertical and one horizontal.

The next step is to make one symmetry plane vertical and one horizontal, or, in other words, make two of the directions *X*, *Y*, *Z*, horizontal and one parallel to the axis of the microscope. Attention is called to the fact that the verniers of both the other horizontal axes (i.e., the outer E–W and N–S horizontal axes) still read zero. The ray which is vibrating parallel to the N–S nicol is one of the critical rays vibrating parallel to *X*, *Y*, or *Z*. The N–S horizontal axis is parallel to this vibration direction. Therefore, this axis (N–S) lies in each of the other two optic symmetry planes and a rotation on it in one direction tends to make one of these planes parallel to the N–S nicol, and in the other direction to make the other plane parallel to the nicol. The grain is now at extinction which is the only criterion under the circumstances for knowing when an optic symmetry plane is parallel to the nicol. Therefore, on the outer stage E–W horizontal axis rotate a few degrees thereby causing the crystal to depart from extinction. Then rotate on the N–S horizontal axis (now slightly inclined) in either direction until extinction is secured. Now return the outer stage to its zero reading and the crystal is oriented for the universal stage. The last rotation on the N–S horizontal axis can commonly be made either way. It can be made in only one direction if one of the other optic symmetry planes that is being sought is dipping steeply. Then a small rotation in one direction brings extinction and a large rotation in the other direction may fail to bring extinction. If it is possible to obtain extinction both ways, then all three symmetry planes may be made parallel to the nicols, two at a time; also, all three rays vibrating parallel to *X*, *Y*, and *Z*, may be transmitted, two at a time.

Optic axial angle.—Knowing the orientation of the grain, the operator turns next to a determination of the optic plane and a measurement of the optic angle. Rotate the nicols to the 45-degree position (or, if the microscope is not equipped for the simultaneous rotation of the nicols, rotate the stage of the microscope). Then rotate the crystal from its oriented position, first using the outer stage E–W horizontal axis and second the N–S horizontal axis. If, on either rotation, extinction is reached, then this extinction position is an optic axis position. Since the nicols are at 45 degrees to the planes of symmetry, which in turn include the only possible vibration directions for the orientations being used, then it is only when the direction of transmission is parallel to an optic axis that the plane of vibration of the polarizer is not rotated in the mineral, and extinction results. The optic axis position may be checked readily by rotating either the nicols or the stage of the microscope—extinction should persist. Measure the angle of rotation required—either it or its complement (corrected for refractive index as shown below) is V. If the optic plane proves to be the E–W (i.e., the first selected) symmetry plane, then it is well to rotate the mount through 90 degrees on the outer stage vertical axis. Then the symmetry plane is in the N–S position and V may be measured on the vernier scale of the outer stage E–W axis. If neither of the vertical symmetry planes is the optic plane then the horizontal plane must be the optic plane. It may or may not be possible to make this plane vertical. If not, then a slight movement of the grain is likely to be sufficient to give a more favorable orientation. The entire procedure must, of course, be repeated again, but with very little practice it should take only a few minutes.

Unless the substance is one of weak birefringence readings of quite satisfactory accuracy [1] may be obtained for 2V by direct measurement if the proper conditions required for the illumination of the stage are observed. These are given in a later paragraph. If for any reason the optic angle is not measured directly, it can easily be calculated from the determination of refractive indices toward which this procedure is leading. Or 2V may be obtained from Wright's graph (Plate IV).

Universal Stage Conditions.—In general all crystals are oriented on the basis of extinction. To recognize an extinction position accurately is essential. As pointed out by Wright and others the correct position is not always the darkest as it would be for perfectly parallel light, but it is a position of comparative darkness, the intensity of which does not change on the various selected rotations. Some prefer to insert a sensitive tint plate over a crystal at extinction, reduce the ocular diaphragm to exclude the effects of other crystals and note changes in the sensitive tint as a test of extinction.

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[1] Wright describes a method that is still more accurate but quite lengthy and tedious. It consists in plotting the optical curves of Fedoroff in projection and locating the optic axis at the midpoint of intersection. See Methods of Petrographic Microscopic Research, Washington, 1911, p. 179.

The conditions required for universal stage work are given in modern texts on the subject. For crystals of strong birefringence fewer precautions are necessary. However, since most crystals, commonly handled, do not have strong birefringence, it becomes necessary to employ added refinements of procedure for which we are largely indebted to Berek.[2] The light should be as nearly parallel as possible. To obtain this, the diaphragms above and below the polarizer should be closed. Also, the diaphragm in the objective, if one is available, should be closed to exclude reflections, but quite satisfactory results can be obtained without this. With these diaphragms closed, an intense light is employed, for which an arc lamp serves well. If monochromatic light is employed from a monochromator, then the diaphragms need not be closed, as other conditions supply the parallelism required. A low power objective is used.

The stage should, of course, be properly centered so that the three vertical axes coincide and the three horizontal axes are properly aligned with the nicols or cross hairs. To check the alignment of the horizontal axes, the simplest procedure is to raise the objective until it is focused upon the surface of the upper hemisphere, then rotations on the horizontal axes should cause dust particles in focus to move parallel to the cross hairs.

Directions of light transmission within crystalline grains mounted on the universal stage are modified on entering the upper hemisphere in quite the same way that these directions are modified on passing into the air from a microscope slide. If the crystal has a refractive index greater than that of the upper hemisphere, then the apparent direction of transmission makes a greater angle with the perpendicular to the inner stage than does the true direction of transmission. Two or more hemispheres of different refractive indices are, therefore, provided for convenience. Apparent angles, as read on the scales of the horizontal axes of the universal stage, are simply corrected by knowing the refractive indices of the hemisphere and of the crystal.

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[2] M. Berek, *N. Jahrb. Min. Beil. Bd.* XLVIII, 1923.

For this purpose a graphic solution is provided in most texts, designed after Fedoroff. This is reproduced in Plate I. Therefore, all vertical angles as read on the arcs of the universal stage must be corrected by this diagram to obtain true values. There is here also the added advantage over thin sections that for this correction in working with powdered material the exact indices are known. It is sometimes advantageous when a large angle is to be read to use a high-index hemisphere, even on a crystal of comparatively low index, as this decreases the apparent angle.

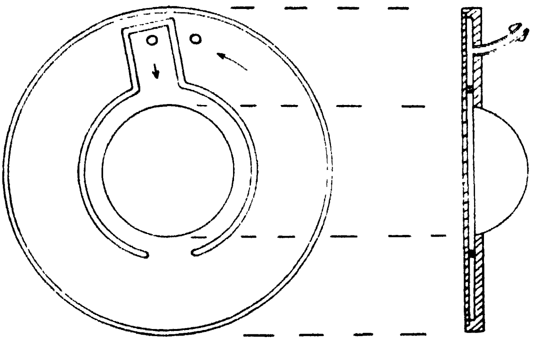

FIG. 176.—Temperature cell for index-variation methods.

Temperature Control.—In order to apply the principles of the double variation method of crystal determination it is necessary to be able to control and vary the temperature of the mount at will. To accomplish this, a special water cell has been designed for the universal stage, and is intended to be connected in series with the water circuit of the refractometer. The cell is shown in Fig. 176. It consists of a metal disk in the center of which is mounted the lower hemisphere. This constitutes the lower side of the cell. The upper side is the central glass disk of the universal stage cemented to the metal disk along a raised margin. This is so adjusted as to leave a space between the metal and glass disks equaling in dimension the thickness of a microscopic slide. It is through this space that water flows. The water is so directed by partitions that it flows directly across the center of the cell and returns around the margin. The intake and outlet tubes lead from the lower surface of the cell at one side. The cell is designed, of course, to fit in the place of a central glass disk of the stage. In making mounts no slide is used, but a cover glass is placed directly on the upper surface of the cell, then the mount on this cover glass and another cover glass over this. The upper hemisphere is then clamped into position—all with suitable liquid contacts. The glass of the cell and the upper hemisphere is protected from injury by the mount by the cover glasses. These cover glasses suffer considerable scratching from hard crystals.

Mounting procedure.—The procedure for mounting thin sections differs somewhat from that for mounting powdered material. For thin sections place a drop of oil on the central glass disk and one on the top of the cover glass of the slide. The lower and upper hemispheres are then put in place, all contacts being made with oil. The oil should have an index near that of the glass. The procedure is standard. If the powder mount is being made without the water cell described above, then a standard mount is made on a slide in a suitable liquid, and suitably covered. This is then mounted in the same manner as the thin section. If the water cell is used, then the powder is mounted between two cover glasses. All contacts are made with the same liquid to avoid possible contamination. If has been stated that the upper surface of the cell is at a height on the stage equivalent to the upper surface of a glass slide resting on the standard glass disk. Therefore, the powder mounted on the water cell, without a glass slide, is at a proper elevation. The particular immersion liquid used is one selected after a brief study of the substance in the ordinary way. The greater facility of the daily procedure makes a cursory examination in this way highly desirable before attempting to use the universal stage.

The determination of refractive indices.—The Becke line method, when employed with the universal stage, is outstandingly satisfactory. The commonly given text-book explanation that the Becke line results from light refracted at a surface between two substances that is perpendicular to the cover glass is doubtless satisfactory in some instances in thin section work. But most petrographers do not rely upon this explanation for immersed powders; rather, the effect results from the roughly lenticular shape of the grain. It is dependent for sharpness, then, upon parallel light, an effect that is commonly gained by lowering the substage. The universal stage with the added distance between the microscope stage and the mount is, therefore, particularly well suited to the Becke line method. This is well borne out by experience, for a suitable mount on the universal stage gives a very strong Becke line with both white and monochromatic light, using a low power objective. When using white light, if the index of the crystal and that of the liquid coincide for light of one wave length, then the dispersion of the rays is very marked unless the dispersion of the crystal is high, and nearly equal to that of the liquid. In short, the Becke line on the universal stage is at least as satisfactory as under the most favorable circumstances in standard use. Therefore, by employing monochromatic light of variable wave length, a very accurate coincidence of indices can be secured.

It is almost always possible to rotate any grain on the universal stage sufficiently to make two of the symmetry planes of the optic indicatrix perpendicular; that is, to secure two of the principal rays. But it is not often possible to rotate from this position through a sufficiently large angle to secure the third principal ray. It is possible, however, to rotate through a considerable angle on the horizontal axis that is perpendicular to the plane of the vibration of the polarizer, though it may be necessary first to rotate 90° on the vertical outer stage axis. Now the refractive index may be measured in this new position. Knowing the refractive index before rotation on the horizontal axis and knowing the angle of rotation (corrected for refractive index—Plate I) and the difference in index, therefore, it is possible to calculate the correct extrapolation to obtain the other principal index at 90° to the first. The greater the extrapolation the less accurate will be the final determination but, fortunately, it is usually possible to rotate through a considerable angle. To facilitate this detail of the procedure a graphical solution of this calculation is offered in Plate II. This diagram[3] holds for any direction of rotation within a plane of symmetry of a biaxial crystal. All angular measurements are made from principal positions.

Even though the double variation method of index determination is used, it is not always possible to bring about sufficient variation to reach the second principal index after the first has been determined. For such crystals of rather strong birefringence if the second index, on rotation on a horizontal axis perpendicular to the plane of vibration of the polarizer, approaches the first, which it must do half the time, then by the following procedure both the second and third indices may sometimes be determined. Rotate sufficiently to bring the second index within range of the liquid and determine it. Then continue to rotate in the same direction as far as possible toward the third critical position and make another determination. Using the diagram (Plate II) after correcting for indices (Plate I), locate two points on the proper degree of rotation lines such that the vertical (or horizontal) intercept of the points indicates the proper index difference obtained from the two readings. Also both points must fall on the same inclined line. This inclined line gives at its extremities the total difference in index between the second and third principal rays. On the ordinate and abscissa can be read the difference in index between the principal indices and those determined. Therefore, the principal indices can be determined by simple addition and subtraction. If the crystal is one of strong birefringence, then this procedure fails.

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[3] In constructing this graph I have consulted with R. W. Babcock of the Department of Mathematics and have received considerable help from him on the proof of it.

Attention should also be called to the fact that if the critical positions in which the principal rays are transmitted are not accurately secured, the error in index is very small indeed, as may be read from the diagram. However, if the positions in which partial birefringence is read, especially near 45°, are not accurately determined then the error is considerable.

Summary of procedure.—The substance under study in powder form is cursorily examined on an ordinary glass slide to locate roughly its position on the refractive index scale. This information is used to select the proper " double variation " liquid for detailed study. A very few grains are then mounted between two cover glasses in the chosen liquid and are placed on the universal stage with the same liquid contacts, using the special water cell. One grain is centered and the upper hemisphere clamped in place. Using the direct illumination of an arc lamp, orient the grain so that X, Y or Z is parallel to the axis of the microscope. Then determine the indices of one or both of the rays transmitted, using temperature and wave-length variation. Rotate in a plane of symmetry to the third critical position if possible and determine the third index. Or, if this is impossible, then rotate as far as possible toward this position and determine the index. By using Plate II, extrapolate to obtain the correct index. The first index determined by the double variation method usually gives the dispersion curve for the substance. For the other indices any one point of the dispersion curve, that is, a determination at any one wave length, is often sufficient, since for many substances the dispersion for the various rays is almost equal.

By the method outlined here all three indices of refraction of any one grain of a biaxial substance of moderate or weak birefringence may be determined with both accuracy and comparative speed. The limiting factor lies in the index range of the immersion medium at the maximum suitable variation of temperature and wave length.

Discussion of Corrections and Calculations.—The rotations of the universal stage are complicated to follow in making necessary corrections for directions of light transmission. They are considerably simplified, however, if traced out on a stereographic projection such as the Wulff net or on the more convenient net shown in Plate III. This plate is a stereographic projection on which are marked rectilinear coordinates and three sets of rotations about the center in ten-degree intervals. When the horizontal axes of the universal stage read 0° then the perpendicular to the inner stage is located at the center of the projection. If, now, to find *X*, *Y* or *Z*, the inner E–W axis is rotated 30° S, then the new position of the perpendicular is found by tracing downward on the central vertical line to the intersection of this line with the 30° great arc. Assume that the stage is rotated (as the next step to find *X*, *Y* or *Z*) on the N–S axis 30 ° W., then the movement of the perpendicular may be traced westward parallel to one of the horizontal *straight* lines to the intersection with the 30° N–S great arc.[4] This makes *X*, *Y* or *Z* parallel to the axis of the microscope. To find the angular distance of the perpendicular to the inner stage from the axis *X*, *Y* or *Z* measure on the concentric 10° circles radially from the center interpolating for the final figure. It is slightly over 41°.

Typically, the optic axis is located next. Suppose, for instance, that a rotation of 40° N on the outer E–W axis makes an optic axis parallel to the axis of the microscope. (This is a normal rotation for the purpose.) Measure 40° N parallel to a straight vertical line counting on the E–W great arcs. This point is 29° from the center. The optic angle, 2V, is then twice 40°, if the hemisphere and crystal agree in refractive index; but they never do. A correction is necessary to learn the true direction of the path of the light within the crystal; it is based on the relationship between the index of the hemisphere and the index of the crystal, and the angle made by the perpendicular to the inner stage with the axis of the microscope. It is expressed as a modification of this angle. In order to correct the reading of the angle V, therefore, two angles must be corrected, 41° and 29°, and the angle V is then read between the corrected points on the diagram (Plate III). If the index of the hemisphere is 1.516 and the index of the crystal is 1.600, the readings 41° and 29° correct to 39° and 27.5° by the method shown in Fig. 177 as applied to Plate I. A correction is diagrammatically represented in Fig. 178. The corrected points 39° and 27.5° are plotted on the radials through the original points 41° and 29°. The angular distance between these corrected points is now measured, counting on the E–W great arcs. This distance is the true angle V.[5] In actual practice the indices of the crystal are learned first and *the correct indices for the specific directions of transmission are used,* unless the crystal is one of weak birefringence, in which case an average index is satisfactory.

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[4] These readings on the horizontal axes are taken directly from the instrument after *X*, *Y*, or *Z* is oriented. They are found on the Wright arcs.

A calculation, the aim of which is to determine one index by extrapolation from another may be carried out with the aid of Plate II. If a uniaxial crystal is oriented with the optic axis parallel to the axis of the microscope, and it is not possible to rotate far enough to make the optic axis perpendicular to the axis of the microscope (which is the position needed to obtain N_e), then rotate as far as convenient, correct the observed angle of rotation on Plates I and III (see last paragraph) and measure the two refractive indices in this position. One is N_o and the other is N'_e. To find N_e use Plate II. Locate the index difference (between N_o and N'_e) on the ordinate or abscissa according to whether N'_e is less than or greater than N_o. Follow horizontally (or vertically) to the inclined line which indicates the number of degrees of rotation (corrected), then on the other coordinate is the figure to subtract (or add) to N'_e to give N_e.

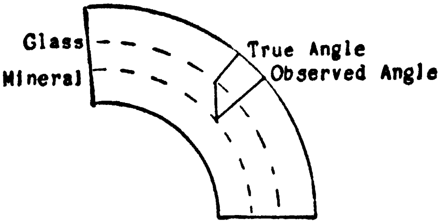

FIG. 177.—Method of correction of observed angles by means of Plate I.

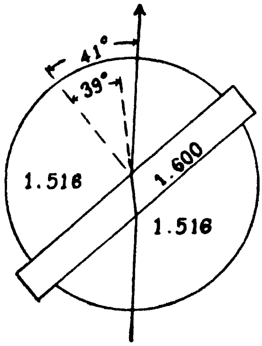

FIG. 178. — Explanation of corrections of observed angles by means of Plate I.

If the crystal is biaxial, then, on a bisectrix or optic normal grain, measure two indices. Here, as with uniaxial crystals, it is usually not possible to rotate a full 90° to the third critical position. The same Plate (II) facilitates the extrapolation. Rotate as far as convenient toward the third critical index, and measure the new index. Care must be taken in making this rotation to note which ray is being transmitted and to rotate on a horizontal axis that is perpendicular to the plane of vibration of the lower nicol. The index difference and the corrected rotation are then used on Plate II as was done for uniaxial crystals and the correct third index is obtained.

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[5] The line joining the corrected points is seldom parallel to one of the ordinates, but is slightly inclined. This introduces an error in measuring the angle between them, but this error is regarded as negligible unless one set of hemispheres is used for the entire index range.

From the three refractive indices thus determined, the optic angle may be calculated from Wright's diagram (Plate IV). Maximum birefringence is found on the abscissa and $N_g - N_m$ or $N_m - N_p$ is found on the ordinate. At the intersection of these, the inclined lines indicate V or its complement.

Rotation corrections are best traced out in the order in which they are made. An example will serve the purpose (see Fig. 179 and the copy of the data sheet for the same figure given on page 141). At the top of the data sheet are recorded the rotation readings for critical positions of the crystal. The first two readings place the crystal in such a way that *X*, *Y* or *Z* is parallel to the axis of the microscope. The third and fourth readings place the two optic axes in a position parallel to the axis of the microscope. These rotations must be followed out first on Plate III, which traces the movements of the perpendicular to the inner stage on the various rotations. It happens that in this example the first two rotations are small; usually they are larger than this. First, follow a *straight* line north 0.5° from the center on Plate III. Then, from this point follow a *straight* line west 5.2°, counting on the great arcs which run from north to south. Now count the angular distance from the center along a radial line, counting the degrees on the concentric circles. This value, 5.2°, is more than either of the rotations used to make it up, but it is essentially the same as one when the other is approximately 0°. It is the observed or apparent angle between the original direction of the light path through the crystal and the present direction; that is, it is the apparent angle between the perpendicular to the inner stage and one of the principal directions. It must be corrected for the difference in index between the crystal for this direction and that of the hemisphere (Fig. 178). The index of the crystal for white light (about 550 $m\mu$) (ray No. 1) is approximately 1.542. Turn to Plate I. Find the reading 5.2° on the circumference, trace radially to the index of the mineral 1.542, follow a vertical line to 1.649 (the index of the hemispere) and follow thence a radial to the circumference. This gives the corrected value as 5.6°. Spot this point on Plate III.

DATA SHEET *6*

Mineral *Cordierite* Locality *Bodenmais*

Inner E. W. Axis	*0.5° N*	Hemisphere	*1.649*
N–S Axis	*5.2° W*		
Optic Axes— 1	*54.3° N*		
2	*53.5° S*	Liquid	*8*
2V–Direct	*61.5°*		
2V–Calculated	*58°–62.8°(C–F)*		
Extinction Angle		Apparatus	*III*

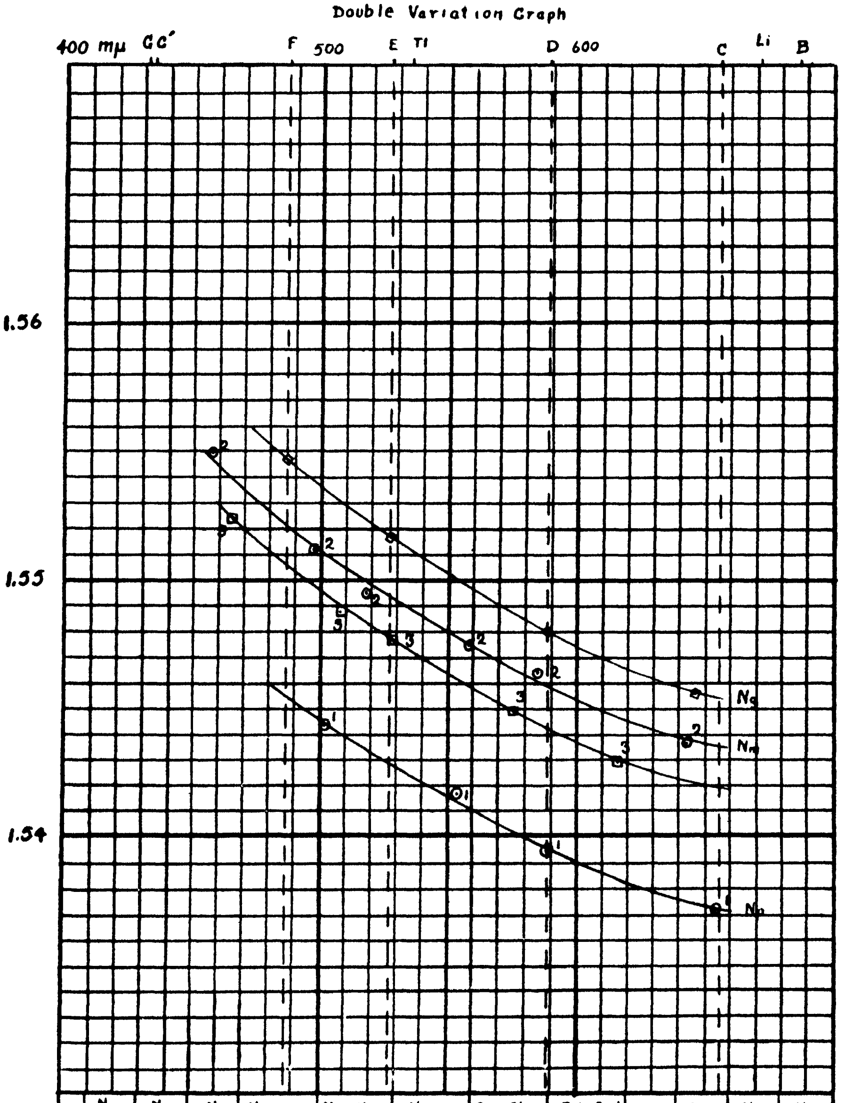
Ray	T. 1	T. 2.	λ	Ref.	Cor.	Index	Rot. °	From	Rot. ° Cor.
1	*26° C*	*26° C*	*654*	*1.5438*	*−.0068*	*1.5370*			
2	*25.5*	*25.5*	*559*	*1.5434*	*+.0040*	*1.5474*			
3	*25.2*	*25.2*	*576*	*1.5432*	*+.0017*	*1.5449*	*45° N*	*1*	*48.6°*
3	*33.8*	*33.8*	*528*	*1.5387*	*+.0089*	*1.5476*	"	*1*	"
1	"	"	*589*	*1.5394*	. .	*1.5394*			
2	"	"	*519*	*1.5389*	*+.0106*	*1.5495*			
2	*38.9*	*38.6*	*407*	*1.5360*	*+.0151*	*1.5511*			
1	"	"	*553*	*1.5368*	*+.0049*	*1.5417*			
3	*38.5*	*38.3*	*509*	*1.5361*	*+.0126*	*1.5487*	"	*1*	"
3	*50*	*49.5*	*465*	*1.5293*	*+.0231*	*1.5524*	"	*1*	"
1	"	"	*501*	*1.5300*	*+.0122*	*1.5422*			
2	"	"	*458*	*1.5300*	*+.0250*	*1.5550*			
2	*21*	*21*	*585*	*1.5460*	*+.0005*	*1.5465*			
3	"	"	*616*	*1.5460*	*−.0030*	*1.5430*	"	*1*	"
2	*14.5*	*14.8*	*642*	*1.5491*	*−.0057*	*1.5434*			

The optic axis, or, if possible, both optic axes are to be located next. From the uncorrected position of the principal direction, already located, follow a vertical line north 54.3° (see data sheet) counting the degrees on the great arcs extending from the west to east poles. Measure the angular distance radially as before. It must be greater than 54.3°, but in this case only slightly greater, about (54.4°). Correct it on Plate I, using the value of the index for the mean ray in white light (1.548), which gives a corrected value of 59.7°. Spot this point on Plate III. Similarly, measure south 53.5° and correct this on Plate I (58.7°) and spot it on Plate III. The distance between the two corrected points spotted on Plate III, as measured in a straight line counting on the east-west great arcs, is 2V. Or, if the second optic axis could not be found, as is commonly the case for wide angles, then the distance to the position of *X*, *Y* or *Z* is V. In this example, 2V is 118.5° about the obtuse bisectrix, and 2V about the acute bisectrix is 61.5° for white light.

Rotation readings for ray No. 3 may be corrected next. As an example choose the first rotation reading, on the data sheet. The corrected index for the new position at 45° N from ray 1 is 1.5449. This figure, 45°, corrected on Plates III and I, as above, becomes 48.6°. The difference in index between this value, 1.5449, and the value (1.5402) on the curve for ray No. 1 at the same wave length (576 $m\mu$) is .0047. That is, the rotation of 45° (or crystallographically 48.6°) from ray 1 has caused an *increase* in the index of .0047, and this is approximately one half the increase necessary to reach the true value for ray No. 3. On Plate II find this value (.0047) on the abscissa. (If this were an index decrease then this value should be found on the ordinate.) Follow a vertical line to its intersection with the inclined line for 48.6°. Then on the ordinate is the additive correction +.0038, which is the remaining difference in index for the balance of the rotation from 48.6° to 90°. This value added to 1.5449 gives a point on ray 3 (N_g), 1.5487. So also for other points. Or, as an alternative procedure, if all rotation readings are made at the same angle of rotation (45°) then draw the dispersion curve through these points and use index values for the Fraunhofer lines as is done in the example (Fig. 179).

It remains to calculate the optic angle from the indices, as a check. Find $N_g - N_p$ and $N_g - N_m$ (or $N_m - N_p$) for the wave lengths desired. On Plate IV, trace these values to their intersection and follow the inclined line to the right-hand side. This gives the value for V (or its complement).

The optic sign may be read from the dispersion curves. If the curve for N_m is closer to that for N_p than to that for N_g then the crystal is positive and in the opposite case it is negative.



	Ng	Nm	Np	Ng-Np	Ng-Nm	Nm-Np	2V-Obs.	2V-Cal.		Ng	Nm	Np
F	1.5548	1.5521	1.5456	.0092	.0027	.0065	white	62.8	F-C	.0094	.0086	.0084
E	1.5518	1.5495	1.5429	89	23	66	light	61	F-D	68	62	61
D	1.5480	1.5459	1.5395	85	21	64	61.5	59.5	D-C	26	24	23
C	1.5454	1.5435	1.5372	82	18	63		58	E-D	38	36	34

Crystal _Cordierite_ Data page _6_ Name _R. C. E._

FIG. 179.—Dispersion curves for cordierite as determined by the double variation method.

DIRECTIONS FOR LABORATORY WORK

Microscope requirements for the universal stage.—Modern petrographic microscopes are made to receive the universal stage. They have two threaded holes on the stage to receive thumb-screw clamps of the universal stage, they have a removable ring in the center of the stage which permits the rotation of the largest circle on the universal stage, they have a clamp which locks the stage in any position of rotation, and they have long racks which permit raising the tube of the microscope sufficiently to introduce the universal stage between the objective and the microscope stage. In addition it is very desirable that they should have a diaphragm below the polarizer, and some use diaphragms in the ocular and objective, but these additional features are essential only for critically accurate work. Quite satisfactory practice work and, for that matter, a great deal of routine work can be done without the extra diaphragms commonly recommended.

Adjustments for the universal stage.—Remove the circular disk from the microscope stage, thereby enlarging the opening of the stage. Raise the tube of the microscope up high and place the universal stage on the microscope stage in such a way that the thumb screw holes of the two coincide. Then insert and adjust the thumb screws so that the universal stage is held loosely. Place the central glass disk or the water cell in position (according to whether a thin section or powder is to be studied). Insert a carefully centered low power (36 mm. or No. 1) objective[6] and focus on the glass surface. Rotate the inner or outer ring of the universal stage (both rotate on a vertical axis) and note the center of rotation through the microscope. Move the whole universal stage on the stage of the microscope until the center of rotation coincides moderately well with the cross hairs. Then tighten the thumb screws, thereby holding the stage firmly in this position. The holes for the thumb screws are made slightly large to permit this adjustment. Now the stage is properly centered. It is well, however, to check this by rotating successively on the inner stage vertical axis, the outer stage vertical axis and on the microscope stage. Some degree of tolerance should be permitted in the construction of the instrument.

Now rotate the whole stage, if necessary, to place the drum on the right-hand side, and clamp the microscope stage. It remains to make this position accurate—that is, to find the zero position of the microscope stage. Since the thumb screw holes allow a certain amount of play, this position should be checked each time the stage is fastened in place. Berek recommends the following simple and ingenious method. Fasten an upper hemisphere in place. Focus upon the upper surface of this hemisphere and note a dust particle near the N–S cross hair. Using either E–W horizontal axis of the universal stage rotate back and forth. By unclamping and rotating the microscope stage as much as necessary this dust particle can be made to remain an equal distance from the N–S cross hair on the rocking rotation. Then once more clamp the microscope stage and make a notation of the vernier reading so as to be able to return to it, if necessary. If the microscope includes a modification which permits the simultaneous rotation of the nicols, then, before this last step is taken, the rotating nicols must be placed in one of the cardinal positions—preferably with the nicol bar at the left side of the microscope.

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[6] Bausch & Lomb now provide a small upper hemisphere permitting the use of a 16-mm. objective with the universal stage.

Illumination conditions.—For practice and for considerable routine work the operator may use ordinary conditions of microscope illumination—either north sky light or a microscope lamp. For accurate work precautions must be taken to secure parallel light. They are—use a powerful source of light, a focused arc lamp is preferred (caution—be very careful to keep the nicols crossed, when using an arc; otherwise the eye may be harmed); use the plane mirror; close the diaphragms above and below the polarizer; to exclude other crystals from the field close the ocular diaphragm; if the operator is bothered by light entering the field by reflections from the surface of the upper hemisphere, then close the diaphragm in the objective.

Making a mount.—Thin sections are very simply mounted. Insert the glass disk and place a drop of oil (such as cedar oil) on it. Rest the thin section on this, thereby securing an oil contact. Add a drop of oil to the top of the thin section and place the upper hemisphere over this. Before fastening the upper hemisphere, turn the thin section with its long dimension across the holder of the upper hemisphere,—in this position manipulation of the thin section is easier. Now examine the thin section and center the crystal of interest; clamp the upper hemisphere in place. Add a drop of oil to the upper surface of the lower hemisphere and fasten it in place. The hemispheres should have an index as close as possible to that of the crystal being studied.

A powder mount on a slide in immersion oil is made in the same way, except that the contact liquid above the central glass disk is the same as the immersion liquid.

If the water cell is used for the double variation procedure, then the mount is made as follows. Place the water cell in the position of the central glass disk. On this, place a drop of the immersion liquid to be used and put a cover glass over this. The surface of the water cell is thus protected. Add a drop of the immersion oil on top of this cover glass, and place a few grains of the substance in this oil. Cover this with another cover glass with another drop of liquid over it. Now place the upper hemisphere in position and loosely adjust it. A satisfactory way to handle the powder in making the transfer to the oil is desirable, since too much or too little is always inconvenient. One good method is to keep a biological needle handy. Dip this in the drop of oil and touch the moist end to the number of grains wanted. Once more dip the needle in the drop of liquid which receives the grains and dry the needle carefully to avoid contamination with another liquid later.

It remains to center a grain. Examine the microscope field and select a suitable grain. Tilt the stage and, if necessary, move the hemisphere slightly with the thumb screw clamps so that the selected grain may be made to fall to the center. By tightening the hemisphere the grain can be held securely in place. Too much pressure is to be avoided as it strains the grain (and destroys extinction) or crushes the grain.

There is another satisfactory procedure, favored by students, which should only be used with caution. Instead of selecting small grains exclusively, select one or two grains of slightly larger size (1 mm.). Roughly center a grain and tighten the upper hemisphere. A surprisingly small pressure serves to shatter the grain and it has been learned empirically that the resulting sizing is more uniform than would be expected. On tilting the stage the small material will move, but quite a fair proportion will remain fixed. Without further centering select a grain to study. Cells are rarely damaged by this procedure, but, since it does place a strain on the cell, caution must be used.

Students almost invariably have difficulty in selecting a suitable grain at first—one that gives a satisfactory Becke line and does not move on tilting the stage. After a little practice the difficulty as invariably disappears. The grains which give the best Becke lines are those which have neither too sharp nor too blunt edges. In this too the student soon becomes proficient. At the end of one or two weeks students seldom need further instruction.

Orienting a uniaxial crystal.—Having selected a grain, tilt the stage at a few extreme angles to be assured that the grain is fixed. If the water cell is used, turn on the water circulation to eliminate air within the cell. Then turn the grain to extinction, using the inner stage vertical axis. (It is assumed, of course, that the outer stage vertical axis is at a cardinal position and that the horizontal axes read zero.) Using the main E–W axis, tilt the stage 30°–40° both ways, and repeat on the N–S axis. If, on either rotation, the crystal remains at extinction, then it is probably uniaxial. Rotate 90°, if necessary, on the inner vertical axis to make the crystal depart from extinction on a rotation of the N–S axis, and, on this axis, rotate a given number of degrees, say 30°. The crystal is not now at extinction. On the inner E–W axis rotate either way to bring extinction.[7] (There are two extinction positions 90° apart crystallographically. One leads to a horizontal position of the optic axis, the other to a vertical position.) Then reverse the 30° rotation to bring the N–S axis to its zero reading. The optic axis is vertical or horizontal. To check this, turn the nicols (or the stage) to the 45° position. If the optic axis is vertical the crystal will remain at extinction. If the optic axis is horizontal it is possible to measure both N_o and N_e at 90° positions with respect to the polarizer. If it is vertical, then it is possible only to measure N_o. A more favorable position should therefore be sought by rotating on any of the horizontal axes either 90° or as much as conveniently possible. In this new position measure both indices (90° apart). If the rotation from the vertical optic axis position was 90° then the indices are N_o and N_e. If it was less than 90° then one is N_o and one is an intermediate index. This can be extrapolated to give N_e by means of Plates I and II as brought out in the text on page 139. Or if, according to the double variation procedure, N_e or N_o cannot be reached in one of the critical positions then rotate to bring the index within the range of the liquid and extrapolate by using Plates I and II.

Orienting an optic symmetry plane of a biaxial crystal.—After turning the crystal to an extinction position, as before, on the inner stage vertical axis with the other axes set at their zero positions, tilt the stage several degrees on the inner E–W and N–S axes and note on which the crystal departs more from extinction. Turn 90° if necessary, on the inner vertical axis to cause the crystal to depart less from extinction on a rotation on the N–S axis. Now with the N–S axis at 0°

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[7] This imparts to the inner stage an attitude inclined to the planes of both nicols. It will be noticed that in this position the entire field becomes gray due apparently to polarization at the water-glass surfaces. If the crystal remains at extinction it should blend with the field and not become darker than the field.

tilt the stage on the inner E–W axis a few degrees [8] (such as 10°) and return the crystal to extinction on the inner vertical axis (now inclined). Try the extinction on a rotation on the N–S axis. If it is improved, then make a further rotation on the inner E–W axis exactly as before and adjust the inner vertical axis to bring extinction. Repeat as often as necessary to bring the crystal to a uniform extinction when rotated both ways on the N–S axis. If, however, the direction of rotation chosen on the inner E–W axis caused the crystal to depart more from extinction at 10° than at 0°, then follow the same procedure by rotating in the opposite direction. This must be done carefully to get good final results. When a rotation on the N–S axis does not disturb extinction, then the first optic symmetry plane is vertical and extends E–W. Clamp the inner stage with the screw provided for the purpose and make a notation of the reading for reference. Clamp the inner E–W axis and make a notation of that reading.

Finding one of the principal directions, *X*, *Y* or *Z* in the first optic symmetry plane (thus finding a second optic symmetry plane).—On the outer E–W axis rotate a few degrees (30°–40°) either way (usually one direction is somewhat limited by the previous rotations, therefore choose the other). This almost always causes the crystal to depart once more from extinction. Now on the N–S axis rotate either way from the zero position until extinction is secured. Sometimes extinction can be secured both ways, 90° apart crystallographically; these are two principal directions. At one of these positions clamp the N–S axis, make a notation of the reading and return the outer E–W axis to its zero position. One principal direction *X*, *Y*, or *Z* is now vertical and the second optic symmetry plane is also vertical and extends N–S. In this position two critical rays are available giving two critical indices, N_g and N_p, or N_g and N_m, or N_m and N_p.

Finding the third optic symmetry plane.—If, in finding the second optic symmetry plane, the trial rotation on the N–S axis yielded two extinction positions, one on each side of the zero position, then find the one not previously chosen and return the outer E–W axis to its zero position. Then the third optic symmetry plane is vertical and extends N–S. If, however, this alternative extinction on the N–S axis rotation could not be found, which is true when one is near the zero position on the N–S axis, then the third symmetry plane is not available without adjusting the upper hemisphere to move the grain and repeating the entire process. It is not necessary to secure the third symmetry plane in order to determine the three refractive indices as will be shown below.

Finding the optic axial plane and measuring the optic angle.—From the position in which a principal direction *X*, *Y* or *Z*, is vertical proceed as follows. Turn the nicols to the 45° position (or unclamp the microscope stage and turn the universal stage to the 45° position); then the crystal is no longer at extinction. Now rotate on the outer E–W axis searching for an extinction position. If none is found return this axis to its zero reading and make a similar search on the N–S axis. Any extinction position found on these rotations is an optic axis. If neither search yields an extinction position then the optic plane is horizontal, in which case it may or may not be possible (see the last paragraph)to find theopticangledirectly. If an optic axis is found then make a notation of the reading and try to find the other optic axis by reversing the direction of rotation—it is commonly not possible to rotate far enough in both directions. The angle between the principal direction and the optic axis is the uncorrected value for V (or its complement). The corrections are given above. If the optic plane was found to be E–W then for accuracy it is well to turn 90° on the outer stage vertical axis and measure V (uncorrected) on the vernier scale of the outer E–W axis. To avoid confusion, however, the notation of the rotation required should be recorded not as north or south, but as east or west.

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[8] If the crystal did not depart widely from extinction on the preliminary trial rotation on the N-S axis then 10° may be too much.

If the optic plane is horizontal and cannot be made vertical then the ingenious method of Berek [9] may be employed to find 2V. It is as follows: On the outer vertical axis rotate 45°. On the outer E–W axis rotate 54.7° crystallographically (i.e., corrected on Plates I and III) in that direction which first makes the perpendicular to the inner stage more vertical. Next rotate the nicols in the same direction as the 45° rotation (or rotate the stage of the microscope in the opposite direction) until extinction is secured. The value of this last rotation is the ordinate of a graph constructed by Berek. 2V is the abscissa. The graph is reproduced here (Fig. 180), but attention is specifically directed to the fact that an error of ½° in the final angle means a large error in 2V (2°–7°). If the angles are calculated

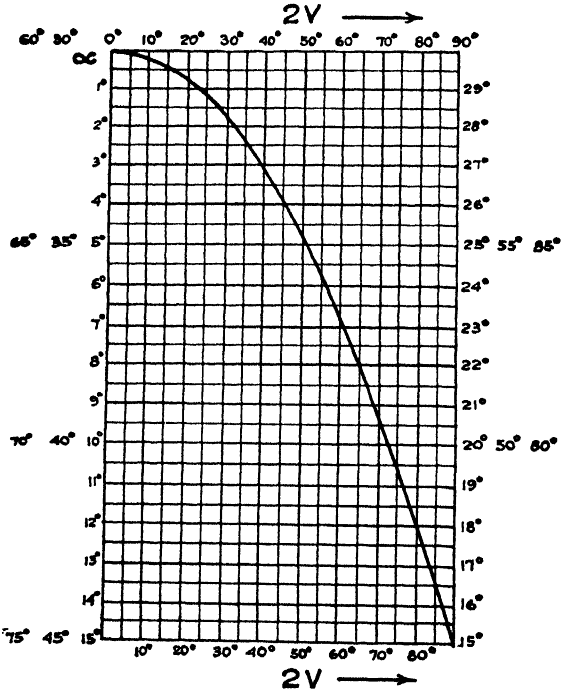

FIG. 180.—Determination of optic angle from the extinction angle, α. (After Berek.)

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[9] *Neues Jahrb. Bl. Bd.* XLVIII, 1923, p. 35.

this degree of error can be reduced, but on the graphs the size of those reproduced here an error of ½° can creep in unless great care is exercised.

Measuring the refractive indices.—For this purpose the double variation method is best adapted. (See Chapter III.) Following the procedure there outlined make suitable changes in temperature and wave length to construct the curves sought (Fig. 123 and Fig. 179). On account of the construction of the universal stage the transmitted light, even with the diaphragms open, is comparatively parallel. Therefore the Becke line method functions particularly well. In fact it will be noticed that the sharpness of a determination is greater with a low-power objective under these conditions than with a 4 mm. (or No. 5) under standard conditions.

There is a routine which the student will do well to follow in determining indices which economizes greatly on his time. It depends on the fact that temperature changes require about five minutes for accuracy whereas wave length changes can be made very rapidly. Three or four temperature changes ordinarily give sufficient information for all three indices of a given substance in accurate routine work. The recommended procedure is as follows: Number the rays 1, 2, 3 to avoid possible confusion. Let No. 1 be that which is transmitted with the nicol bar at the left (or the universal stage drum at the right). No. 2 is the ray which is transmitted with the nicol bar at the front of the microscope (or the drum at the front or back). No. 3 is any reading either directly on the third ray or a rotation reading toward it. For example, set the nicol bar at the left after making a mount and turn on the water at some temperature near that of the room. After a suitable lapse of time determine the wave length at which the Becke line disappears. Record the ray number (No. 1), the temperature, the wave length, and the refractometer reading. Turn the nicol bar 90° to the front position and make another determination and complete record. Now rotate on the outer E–W axis or the N–S axis a convenient amount toward ray No. 3. The amount depends, for some crystals, upon the difference in index. If the difference is great a smaller rotation will be made; otherwise the range of the liquid will not be great enough. For common substances turn as much as conveniently possible. The axis used depends on the position of the inner stage. One axis will permit a greater rotation than the other. Choose the axis first; then, if necessary, turn the nicols 90° to make the plane of the polarizer normal to this axis. Determine the correct wave length as before and make the necessary record, but add to the record the number of degrees rotated and the direction and the ray from which the rotation was made (No. 1 or No. 2). Now change the temperature up or down 5° to 10° according to the wave length already determined. To raise the temperature will impart to the liquid a lower index and it will be necessary therefore to use a shorter wave length of light, and vice versa. The amount of change will depend on the curves for the liquid given in Fig. 122. While the temperature is coming to equilibrium the corrections may be made as shown on the sample data sheet, see page 141. This will consume all of the time required to establish equilibrium. If the corrected points are plotted on the dispersion sheet as the work proceeds a better perspective may be gained and the needs for temperature change can be estimated more accurately. When completed, the dispersion sheet shows three curves; two are those of critical indices and the third is that of some intermediate index.

If the rotation readings were not all at the same number of degrees, then the ray No. 3 points will not form a consistent curve. It remains to correct the points for ray No. 3, thereby securing the third critical curve. After plotting, the numbers may be changed to the proper symbols N_g, N_m, and N_p.

With ordinary care, points should have an accuracy of ±.0004. In careful work this degree of accuracy can be improved. In constructing the curves the error is automatically reduced by averaging.

For the beginning student especially, it is extremely important to follow precisely the routine procedure just described.

PART II

DESCRIPTIONS OF ARTIFICIAL INORGANIC SOLID SUBSTANCES OR ARTIFICIAL MINERALS

PART II

DESCRIPTIONS OF ARTIFICIAL INORGANIC SOLID SUBSTANCES OR ARTIFICIAL MINERALS

I. ELEMENTS

Phosphorus (P) is isometric; crystals dodecahedral. G. = 1.84, F. = 44° C. Burns readily. Isotropic with N = 2.093 C, 2.117 D. 2.158 F. Colorless or yellow. Prepared by reduction of phosphate with carbon.

Selenium (Se) has at least three crystal phases; one is monoclinic with $a : b : c = 1.635 : 1 : 1.610$, $\beta = 75° \ 58'$; crystals thin basal plates or nearly equant with 001 and 111 prominent. G. = 4.47. Color orange red. Another phase is monoclinic with $a : b : c = 1.592 : 1 : 1.135$, $\beta = 86° \ 56'$; crystals short prismatic or thin tabular parallel with 100 or 001. Color dark red. A third phase is trigonal with $c = 1.15$ (?). Crystals hexagonal prismatic with rhombohedral end faces. G. = 4.79. F. = 220° C. Uniaxial positive with $N_o =$ 3.0 (680)[1] 3.00 Na,[2] $N_e = 4.04$, $N_e - N_o = 0.17$ (680 – Merwin [1]) 1.04 (Skinner [2]). Luster bright metallic. Selenium is recovered from flue deposits in the manufacture of H_2SO_4. Isotropic mixtures of fused Se and S are useful immersion media. Indices are given in the following table:[3]

% Se......	100	90	80	70	60	50	40	30	20	10	0
% S.......	0	10	20	30	40	50	60	70	80	90	100
N(Li).....	2.716	2.53	2.40	2.30	2.22	2.16	2.11	2.07	2.03	2.00	1.978
N(Na)....	2.92	2.67	2.49	2.37	2.27	2.20	2.15	2.10	2.06	2.025	1.998
N(Tl).....	.....	....	....	2.43	2.32	2.25	2.19	2.13	2.09	2.05	2.018

Sulphur (S) has five or six different crystal phases. The ordinary low temperature phase is orthorhombic with $a : b : c = 0.813 : 1 : 1.903$.

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[1] H. E. Merwin: *Int. Crit. Tab.* VII, 1931, p. 19.

[2] C. H. Skinner: *Phys. Rev.* IX, 1917, p. 148.

[3] H. E. Merwin and E. S. Larsen: *Am. Jour. Sci.*, 184, 1912, p. 42.

Crystals pyramidal or varied (see Figs. 181–183) with imperfect 001, 110 and 111 cleavages. H. = 2. G. = 2.07. Melts at 108° C. after inversion at 98° C. Insoluble in acids; soluble in CS_2. The optic plane is 010; Z = *c*. (+)2V = 68° 58′ Na, 68° 46′ Tl. N_g = 2.2203 C, 2.2454 D, 2.3172 F, N_m = 2.019 + C, 2.0377 D, 2.087 F, N_p = 1.942 C, 1.957 D, 1.999 F, $N_g - N_p$ = 0.2884 D. Color yellow. Crystallized easily by sublimation as from solution. The natural substance is abundant about some volcanoes and also found in some salt and gypsum deposits.

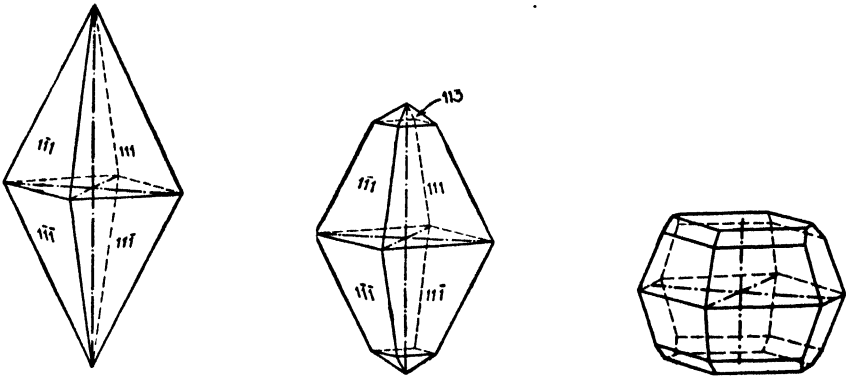

FIG. 181. FIG. 182. FIG. 183.

FIGS. 181–183.—Crystal habits of sulphur.

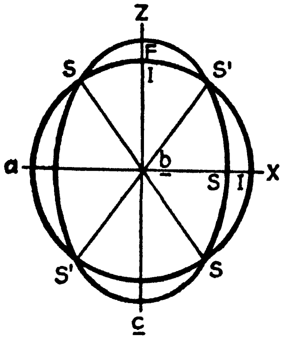

FIG. 184.—Wave-fronts in axial planes in sulphur, differences of velocity being exaggerated.

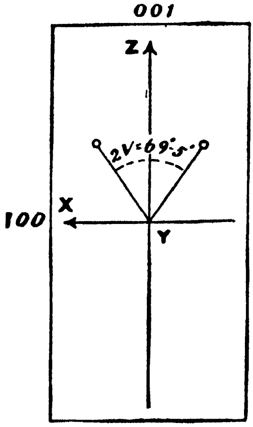

FIG. 185.—Diagram of the optic orientation of sulphur.

Monoclinic sulphur is stable above 98° C. and metastable at lower temperatures. In this phase *a* : *b* : *c* = 0.996 : 1 : 0.9998, *β* = 84° 14′.

H. = 1.5. G. = 1.95. F. = 115° C. The optic plane is 010; $X \wedge c = 44°$. $(-)2V = 58° \pm$ (Na). N = 1.96 (calc.), $N_g - N_p$ = weak. Color honey yellow. Easily crystallized from fusion or from solution.

Other crystal phases are known, but not measured optically.

II. SULPHIDES, ETC.

Sulphides, selenides, tellurides, arsenides, antimonides, and sulphosalts are included in this division, as well as carbides.

1. CARBIDES

SiC is trigonal with $c = 1.226$. Crystals thin basal plates with rare twinning on $10\bar{1}1$ and poor basal cleavage. H. = 9.5. G. = 3.2. Infusible, but dissociates at about 3400° C. Insoluble even in HF. Uniaxial positive with extremely high refringence, strong birefringence and very strong dispersion, as follows:[1]

$\lambda =$	755	671(Li)	589(Na)	535(Tl)	486(F)	Dispersion, F–C (486–656)
$N_e =$	2.654	2.673	2.697	2.721	2.749	0.072
$N_o =$	2.616	2.633	2.654	2.675	2.700	0.064
$N_e - N_o =$	0.038	0.040	0.043	0.046	0.049	0.008

Colorless when perfectly pure, but usually colored green, blue, red, black by small amounts of iron, alumina, carbon, etc., present as impurities. Bluish crystals are pleochroic with X > Z. Further, surface films of silica, commonly present, produce iridescent colors. Luster brilliant adamantine.

Found by Moissan in the Canyon Diablo meteorite and hence known as *moissanite*. It is an important artificial product of the electric furnace. Readily recognized by extreme hardness, extreme refringence and extreme dispersion.

Al_4C_3 is hexagonal[1a] in six-sided basal plates with perfect 0001 cleavage. Uniaxial positive with $N_o = 2.7$ (700 mμ), $N_e = 2.75 \pm$ (700 mμ), $N_e - N_o = 0.05 \pm$. Color yellow.

CaC_2 is orthorhombic[2] (?) and pseudocubic with complex multiple twinning on the dodecahedral face; perfect 001, 010, and 100 cleavages and 110 parting. Combines with water freely to form acetylene and calcium hydroxide. Apparently uniaxial (positive) to (+) $2V = 30°$ with $\rho < v$: the optic plane is parallel with the twinning lines; extinction parallel with the cleavages. N more than 1.75, $N_g - N_p = 0.050$. Color purplish red, yellow, greenish; slightly pleochroic in thicker sections; nearly colorless in very thin flakes. The yellow carbide probably contains other material in crystal solution; it has extinction at about 10° to 24° to the cleavages and is considered triclinic and pseudocubic. Commonly used as a source of acetylene.

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[1] H. E. Merwin: *Jour. Wash. Acad. Sci.*, VII, 1917, p. 445.

[1a] Compound prepared by G. W. Morey; properties determined by H. E. Merwin—personal communication, Mar. 25, 1931.

[2] C. H. Warren: *Am. Jour. Sci.*, CCII, 1921, p. 120. Calcium cyanimide (CaN·CN) is rhombohedral with perfect rhombohedral cleavage at 74° and poor basal parting; twinning rare. Uniaxial positive with $N_o = 1.60$, $N_e > 1.95$, $N_e - N_o$ = above 0.35. Colorless. Often present in commercial "carbide."

2. SULPHIDES

MgS is isometric[3] with perfect 100 cleavage and NaCl space lattice. G. = 2.843 and N = 2.254 C, 2.271 Na, 2.285 Tl. Colorless. Made in the electric oven.

CaS is isometric[3] with perfect 100 cleavage and NaCl space lattice. 2.71 and N = 2.120 C, 2.137 Na, 2.161 (520 mμ). Colorless. The natural substance, called *oldhamite*, is found in meteorites. Made by reduction of $CaSO_4$ in an electric oven.

SrS is isometric[3] with perfect 100 cleavage and NaCl space lattice. G. = 3.913 and N = 2.087 C, 2.107 Na, 2.122 (540). Colorless. Made by reduction of $SrSO_4$ in an electric oven.

BaS is isometric[3] with perfect 100 cleavage and NaCl space lattice. G. = 4.377 and N = 2.140 C, 2.155 Na, 2.183 Tl. Colorless. Made by reduction of $BaSO_4$ in an electric oven.

MgSe is isometric[3] with G. = 4.268 and N > 2.42 Na (2.44, calc.).

CaSe is isometric[3] with NaCl space lattice and G. = 3.806 and N = 2.245 C, 2.274 Na, 2.292 (555).

SrSe is isometric[3] with NaCl space lattice and G. = 4.544 and N = 2.190 C, 2.220 Na, 2.252 (540).

BaSe is isometric[3] with NaCl space lattice and G. = 4.937 and N = 2.230 (675), 2.268 Na, 2.289 (560)

CaTe is isometric[3] with G. = 4.873 and N > 2.51 Na. (2.605 calc.).

SrTe is isometric[3] with G. = 5.218 and N = 2.367 C, 2.408 Na, 2.460 Tl.

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[3] K. Spangenberg: *Naturwiss.*, XV, 1927, p. 266; M. Haase: *Zt. Kr.* LXV, 1927, p. 509; LXVI, 1928, p. 236.

BaTe is isometric[3] with G. = 7.593 and N = 2.370 C, 2.440 Na, 2.520 Tl.

ZnS has two crystal phases [4] as well as an apparently amorphous condition. The low temperature phase of ZnS is isometric with perfect dodecahedral cleavage, the atoms being arranged as shown in Fig. 186. Crystals often tetrahedral, as in Fig. 187. H. = 3.5–4. G. = 4.09. Sublimes in nitrogen at 1178° C. Soluble in HCl. Isotropic with N = 2.34 Li, 2.368 Na, 2.398 Tl. Also may be slightly anistropic probably on account of strain since anistropic areas are easily produced by pressure. With 28 per cent FeS, N = 2.395 Li, 2.47 Na. Color straw yellow when pure, grading to brown and black with increase of FeS. Gray in vertical reflected light. Made by precipitation from alkaline solutions. It is the stable phase below 1020° C., the inversion temperature being lowered to 880° C. by 28 per cent FeS.

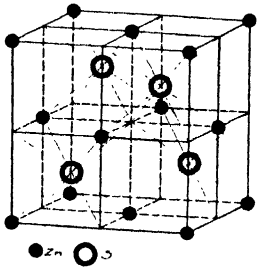

FIG. 186.—Space lattice of isometric ZnS.

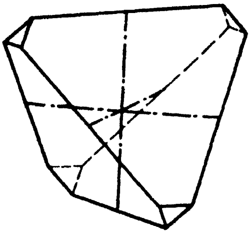

FIG. 187.—Tetrahedral habit of isometric ZnS.

The natural substance, called *sphalerite*, is common in metalliferous veins, etc.

The high temperature phase (α–ZnS) is hexagonal with c = 0.8175; crystals hemimorphic, short prismatic or pyramidal, with good prismatic cleavage. H. = 3.5–4. G. = 4.087. Sublimes in nitrogen at 1185° C. Soluble in HCl. Uniaxial positive with N_o = 2.330 Li, 2.356 Na, Ne = 2.350 Li, 2.378 Na, $N_e - N_o$ = 0.022 Na. With 28 per cent FeS the indices are about N_o = 2.46, N_e = 2.48. Commonly fibrous to lamellar parallel to 0001 with negative elongation. Apparently isotropic when mounted in balsam or methylene iodide, but distinctly birefringent when mounted in a red mixture of sulphur and selenium. Color straw yellow; darker when FeS is present and then weakly pleochroic in yellow with X > Z. Gray in vertical reflected light. Formed artificially only above 200°

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[4] **Allen, Crenshaw, and Merwin:** ***Am. Jour. Sci.,*** **CLXXXIV, 1912, p. 341.**

C. and from acid solutions. It is the stable phase above 1020° C., but may exist as a metastable phase at ordinary temperature. The natural substance, called *wurtzite*, is rare.

Freshly precipitated ZnS is apparently amorphous and very finely granular with the consistence of a stiff jelly. In such a condition the grains are isotropic with $N = 2.18 - 2.25$, or distinctly birefringent (due to strain?) with X parallel to the surface and $N = 2.18 - 2.24$.

ZnTe is isometric[5] with G. = 5.54 and N = 3.56 D. Color red. Formed from fusion.

CdS is hexagonal,[4] hemimorphic, with $c = 0.8109$. Crystals basal tablets or short prismatic with distinct prismatic cleavage. Twinning on $10\bar{1}1$ and on $20\bar{2}3$, producing forms suggesting monoclinic symmetry. H. = 3. G. = 4.82. Sublimes in nitrogen at 980° C. Soluble in HCl. Uniaxial positive with $N_o = 2.431$ Li, 2.506 Na, 2.61 (523), $N_e = 2.456$ Li, 2.529 Na, $N_e - N_o = 0.023$ Na. For $\lambda = 523$ the substance is isotropic (and nearly opaque) and at the blue end of the spectrum it is uniaxial and negative with $N > 2.6$ and $N_o - N_e = 0.016$ at $\lambda = 516$. Sometimes distinctly biaxial. Impure CdS may have indices as low as $N_o = 2.42$, $N_e = 2.44$. Color yellow to orange. Made by vaporizing cadmium in hydrogen sulphide. The natural substance, called *greenockite*, is usually associated sparingly with zinc ores.

HgS has three crystal phases.[4] The only stable phase is hexagonal with $c = 1.145$. Crystals prismatic or tabular with perfect prismatic cleavage. H. = 2–2.5. G. = 8.176. Sublimes at 580° C. in the absence of oxygen. Decomposed by aqua regia. Readily soluble in concentrated solutions of sodium or potassium sulphide. Uniaxial positive with $N_o = 2.81$ Li, $N_e = 3.14$, $N_e - N_o = 0.33$. Color bright red or scarlet. Made by sublimation of the amorphous black HgS. The natural substance, called *cinnabar*, is found chiefly in veins and as a product of solfataric action.

A metastable phase of HgS is isometric, black and opaque, with G. = 7.60. It is formed only from acid solutions and changes to cinnabar under favorable conditions. The natural substance, called *metacinnabarite*, is quite rare.

Another metastable phase of HgS is hexagonal and prismatic with G = 7.2. Uniaxial positive with $N_o = 2.58$ Li, $N_e = 2.82$, $N_e - N_o = 0.24$. Color bright red like cinnabar. Inverts to cinnabar rather easily. Made by precipitation of a solution of sodium mercuric chloride with sodium thiosulphate. Unknown in nature.

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[5] *Int. Crit. Tables*, I, 1926, p. 119.

N_4S_4 is monoclinic[6] with $a : b : c = 0.888 : 1 : 0.848$, $\beta = 89° 37'$. Crystals pseudocubic with lamellar twinning on $\bar{1}01$. G. = 2.2. The optic plane is 010; $Z \wedge c$ = large. (+) 2V = large, N_g = ?, $N_m = 2.046$, $N_p = 1.908\pm$, $N_g - N_p$ = extreme. Color orange red; yellow in powder. Purified by sublimation in a vacuum.

3. SULPHOSALTS

$AgAsS_2$ has two (or three?) crystal phases. The low temperature phase is trigonal with $c = 0.653$. Crystals small prismatic with rhombohedral and basal cleavages. H. = 1.5–2. Uniaxial negative with $N_o = 2.6$ Li, N_e = ?, $N_o - N_e$ = extreme. Color and streak scarlet with X = nearly colorless and Z = pale red. Not yet produced artificially; the natural substance, called *trechmannite*, is very rare. It inverts on moderate heating to a biaxial phase which is perhaps the same as the natural substance called *smithite*; the latter is monoclinic with $a : b : c = 2.221 : 1 : 1.957$, $\beta = 78° 48'$. Crystals six-sided tablets with perfect 100 cleavage. H. = 1.5–2. G. = 4.88. Optic plane is 010; $Z \wedge c = +4°$ Li, $+6.5°$ Na. (−) 2V = 65° Na? (N = 3.27?). Color and streak scarlet vermilion, altering to orange-red. The inversion product from trechmannite is biaxial with (−) 2V = 26° ±, $\rho > v$ strong, $N_g = 2.60$ Li, $N_m = 2.58$, $N_p = 2.48$, $N_g - N_p = 0.12$.

The following salt is a sulpharsenate rather than a sulphosalt, proper, but may be included here for convenience.

$Na_3AsS_4 \cdot 8H_2O$ is monoclinic with $a : b : c = 0.668 : 1 : 0.528$, $\beta = 76° 38'$. Crystals short prismatic. Optic plane is 010; $X \wedge c = +81° 11'$. (−) 2V = 87° 44'. $N_m = 1.6802$, $N_g - N_p$ = weak. Very weakly pleochroic.

III. HALIDES AND CYANIDES

The halides are arranged as simple halides, ammoniated halides and oxyhalides, and simple halides are classified in the order of increasing valence of the metallic element and in the order of decreasing symmetry. Cyanides are included with the corresponding halides.

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[6] G. F. H. Smith: *Mineral Mag.*, XVI, 1911, p. 97.

1. ANHYDROUS HALIDES AND CYANIDES OF MONOVALENT BASES

HALITE GROUP

NaCl is isometric with face-centered cubic arrangement of each kind of its atoms as shown in Fig. 188. Crystals cubic with very perfect 100 cleavage. H. = 2.5. G. = 2.17. F. = easy. Soluble in H_2O. Isotropic with N = 1.5407 C, 1.5443 D, 1.5534 F, F − C = 0.0127. Colorless or tinted by impurities. Crystallizes readily from H_2O solution. The natural substance, called *halite*, is a common salt-lake deposit.

KCl is isometric with the NaCl space lattice. Crystals cubic with perfect cubic cleavage. H. = 2. G. = 1.99. F. = easy with violet flame. Soluble in H_2O. Isotropic with N = 1.4872 C, 1.4904 D, 1.4984 F, F − C = 0.0112. Colorless or tinted by impurities. Crystallizes readily from H_2O solution. The natural substance, called *sylvite*, is found in salt-lake deposits.

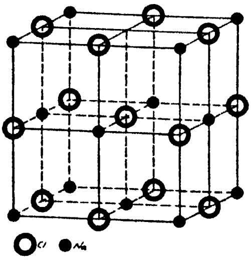

FIG. 188.—Space lattice of NaCl.

NaCl and **KCl** do not intercrystallize in all proportions,[1] but form a series of double salts, which are stable at the temperature of formation, but unstable at ordinary temperature, breaking down into simple halides. The breakdown is sub-microscopic, and causes the measured index of the (microscopically uniform) double salt to be the additive index of intimate mixtures of NaCl and KCl in the given proportions. C. B. Slawson [1] has shown that these facts may be used to determine quantitatively the tenor of Na and K in any mixture of these chlorides as obtained, for example, from a standard rock analysis. The double salts all have perfect cubic cleavage and the following indices:

Salt	N (D)	Salt	N (D)
NaCl (100%)	1.544	$4NaCl \cdot 3KCl$	1.518
$7NaCl \cdot KCl$	1.536	$NaCl \cdot KCl$	1.514
$5NaCl \cdot KCl$	1.533	$2NaCl \cdot 3KCl$	1.5085
$3NaCl \cdot KCl$	1.528	$2NaCl \cdot 5KCl$	1.503
$2NaCl \cdot KCl$	1.523	$2NaCl \cdot 7KCl$	1.500
$3NaCl \cdot 2KCl$	1.519	KCl (100%)	1.490

NaF is isometric with the NaCl space lattice. Crystals cubic with perfect 100 cleavage. H. = 5.5. G. = 2.81. Soluble in hot H_2O.

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[1] *Am. Mineral*, XIV, 1929, p. 293. There is probably also the double salt $9NaCl \cdot KCl$, which would have N = 1.538±.

Isotropic with N = 1.3246 C, 1.3258 D, 1.3285 F, F − C = 0.0039. May have weak negative birefringence at room temperature with red to violet color and X = golden yellow, Z = carmine red. The natural substance, called *villiaumite*, is very rare.

The following salts[2] also have the NaCl space lattice with cubic habit and cleavage:

Salt	G.	N(C)	N(D)	N(F)	F–C
LiF	2.64	......	1.3915		
LiCl	2.07	......	1.662		
LiBr	3.46	......	1.784		
LiI[3]	4.06	.. ..	1.955		
NaBr	3.20	1.6355	1.6412	1.6555	0.0200
NaI	3.66	.....	1.7745		
KF[3a]	2.49	......	1.352		
KBr	2.75	1.5547	1.5594	1.5716	0.0169
KI	3.13	1.6589	1.6670	1.6876	0.0287
RbF[3]	3.74	1.394	1.396	1.399	0.005
RbCl	2.81	1.4903	1.4936	1.5016	0.0113
RbBr	3.35	1.5483	1.5528	1.5646	0.0183
RbI	3.56	1.6397	1.6474	1.6672	0.0275
NH_4I	2.50	1.6938	1.7031	1.7269	0.0331
NaCN	....	.....	1.452		

KCN is isometric in cubes or octahedrons with G. = 1.52 and[4] N = 1.410 ± 0.003 Na.

NaK$(CN)_2$ is isometric and isotropic with[3a] N = 1.465 ±. Colorless.

AgCl is isometric of octahedral or rarely cubic habit without cleavage. It has the NaCl space lattice. H. = 1–2. G. = 5.5. Soluble in NH_4OH. Sectile. Fuses at 452° C. After fusion and recrystallization N = 2.071 D. Color pearl gray, greenish gray or white, becoming violet in sunlight. Apparently miscible in all proportions with AgBr. Natural AgCl is called *chlorargyrite*, natural AgBr, *bromyrite* or *bromargyrite*, intermediate types, *embolite*, and a variant with iodine {Ag(Cl, Br, I)} is known as *iodembolite*, while the whole group is called *cerargyrite*.

AgBr is isometric of octahedral habit without cleavage. It has the NaCl space lattice. H. = 1–2. G. = 6.2. Soluble in NH_4OH. Sectile. Fuses at 422° C. Isotropic with N = 2.252 (589), 2.256 (578), 2.263 (546), 2.363 (436). Color yellow or amber, slightly greenish, with little change in sunlight. Miscible in all proportions with AgI, with which it forms an isodimorphous series, AgI being hexagonal. The isometric phases [5] are stable from pure AgBr to about 60 per cent and metastable to nearly 90 per cent AgI. With 67 mol. per cent AgBr and 33 per cent AgI, N = 2.299 (589), 2.303 (578), 2.320 (546). With 33 mol. per cent AgBr and 67 per cent AgI, N = 2.36 ± (589), 2.40 ± (546). Natural AgBr is called *bromyrite* or *bromargyrite*, while natural Ag(Br, I) it is known as *iodobromite*.

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[2] K. Spangenberg: *Zeit. Kryst.* LVII, 1923, p. 494.

[3] Space lattice may be like CsCl.

[3a] Measured by H. E. Merwin—personal communication, Mar. 25, 1931. Spangenberg gives N = 1.361 D and Wulff (*Zeit. Kryst.* LXXVII, 1931, p. 84) gives N = 1.3629 D for KF.

[4] Measured by V. A. Vigfusson at the University of Wisconsin.

The two following compounds are hydrides rather than halides, but may be included here for convenience since they have the NaCl space lattice.

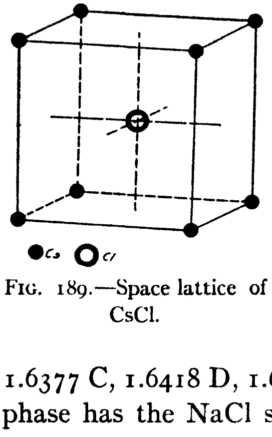

FIG. 189.—Space lattice of CsCl.

NaH is isometric [6] of fibrous habit. N = 1.470. Colorless.

KH is isometric [6] of fibrous habit. N = 1.453. Colorless.

CsCl has two crystal phases;[7] the room temperature phase has the simple cubic arrangement of each kind of its atoms as shown in Fig. 189. Crystals cubic without cubic cleavage G. = 3.97. Isotropic with N = 1.6377 C, 1.6418 D, 1.6523 F, F C = 0.0146. The high temperature phase has the NaCl space latt Crystals cubic with perfect 100 cleavage. G. = 3.56. Isotropic with N = 1.531 C, 1.534 D, 1.543 F, F – C = 0.012.

CsF has two crystal phases;[7] the room temperature phase has the NaCl space lattice. Crystals cubic with perfect cubic cleavage. G. = 5.34. Isotropic with N = 1.575 C, 1.578 D, 1.583 F, F – C = 0.008. The lower temperature phase has the CsCl space lattice. G. = 4.52. Isotropic with N = 1.476 C, 1.478 ± 0.005[7a] D, 1.482 F, F – C = 0.006. Crystals from another source have [3a] N = 1.484 ± 0.002 D.

CsBr has two crystal phases;[7] the room temperature phase has the CsCl space lattice. G. = 4.45. Isotropic with N = 1.6924 C, 1.6984 D, 1.7126 F, F – C = 0.0202. The high temperature phase has the NaCl space lattice. Crystals cubic with perfect cubic cleavage.

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[5] T. Barth: *Am. Jour. Sci.*, XIX, 1930, p. 135.

[6] *Zeit. phys. Chem.* B, VI, 1930, p. 251.

[7] P. Wulff: *Zeit. Elektrochem.* XXXIV, 1928, p. 611. For CsCl, N = 1.6397 D.

[7a] H. E. Merwin: *Jour. Wash. Acad. Sci.*, XII, 1922, p. 250.

G. = 3.75. Isotropic with N = 1.577 C, 1.582 D, 1.594 F, F − C = 0.017.

CsI has two crystal phases;[7] the room temperature phase has the CsCl space lattice. G. = 4.52. Isotropic with N = 1.7784 C, 1.7876 D, 1.8115 F, F − C = 0.0329. The high temperature phase has the NaCl space lattice. Crystals cubic with perfect 100 cleavage. G. = 3.82. Isotropic with N = 1.653 C, 1.661 D, 1.681 F, F − C = 0.018.

TlCl is isometric[5] with the CsCl space lattice. Fuses at 426° C. and recrystallizes on cooling. Isotropic with N = 2.223 (650), 2.247 (589), 2.400 (436). Colorless.

TlBr is isometric[5] with the CsCl space lattice. Fuses at 450° C. Isotropic with N = 2.384 (650), 2.418 (589), 2.452 (546), 2.652 (436). Colorless in thin sheets.

TlI is isometric[5] with the CsCl space lattice above 175° C.; at lower temperature this phase is metastable and inverts to an orthorhombic phase slowly. Fuses at 435° C. The isometric phase has N = 2.72 ± (650), 2.78 ± (589), 2.85 ± (546).

TlBr and **TlI** are miscible in all proportions[5] in the isometric phase. With more than 70 per cent TlI the crystals are metastable at ordinary temperature, but with as much as 80 per cent TlI the crystals often remain isometric for days. Iodine-rich crystals are opaque for violet and blue rays, but nearly as transparent as glass for yellow and even for green. Mixtures of TlBr and TlI are recommended for immersion media for high index of refraction determinations.[8]

Data on indices follow:

TlBr	TlI	650	589	578	546
100	0	2.384	2.418	2.424	2.452
89	11	......	......	.....	2.482
80	20	......	2.468	.....	2.511
70	30	2.455	......	.....	2.541
60	40	......	......	.....	2.578
50	50	2.518	......	2.567	2.616
40	60	......	......	2.615	2.660
33	67	......	......	.....	2.683
25	75	2.610	2.662	2.673	2.722
0	100	2.72±	2.78±	.....	2.85±

CuCl is isometric with the ZnS space lattice. Crystals tetrahedral with 110 cleavage. G. = 4.14. Isotropic with[9] N = 1.955 C, 1.973 D, 1.996 Tl. The natural substance, called *nantokite*, is rare.

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[8] T. Barth: *Am. Mineral.*, XIV, 1929, p. 358.

[9] M. Haase: *Zeit. Kryst.*, LXVIII, 1928, p. 82. Larsen (*U. S. Geol. Surv. Bull.* 679, p. 114) gives N = 1.930 for artificial colorless CuCl.

CuBr is isometric with the ZnS space lattice. Crystals tetrahedral with 110 cleavage. G. = 5.17. Isotropic with[9] N = 2.092 C, 2.116 D, 2.160 Tl.

CuI is isometric with ZnS space lattice. Crystals tetrahedral with perfect 110 cleavage. G. = 5.69. Isotropic with[9] N = 2.313 C, 2.345 D, 2.385 Tl. The natural substance, called *marshite*, may show abnormal weak birefringence. Crystals are yellow.

NH_4Cl has two crystal phases; the low-temperature phase has the CsCl space lattice for N and Cl. Crystals tetrahedral with twinning on 111 and poor 111 cleavage. H. = 1.5–2. G. = 1.53. Isotropic with N = 1.6380 C, 1.6426 D, 1.6529 F, F − C = 0.0149 (Grailich); N = 1.639 ± 0.001 D (Merwin [9a]). Colorless. Reversible inversion at 156° C. to the NaCl space lattice with G. = 1.27. Soluble in H_2O. The natural substance known as *salammonite* or *sal ammoniac*, is found about volcanoes and in lake deposits. NH_4Cl can apparently intercrystallize with chlorides of iron, nickel, cobalt, manganese, copper, cadmium and probably zinc. Neuhaus [10] has shown that in such cases the second component is present in submicroscopic crystals regularly arranged and no isomorphous series exists.

NH_4Br has two crystal phases; the low temperature phase (below 109° C.) has the CsCl space lattice for N and Br. Crystals tetrahedral with G. = 2.44. Isotropic with [4] N = 1.7075 C, 1.7108 D, 1.7163 F. White or colorless.

NH_4F is hexagonal [11] in plates and prisms. Uniaxial positive with N_o = decidedly less than 1.328, $N_e - N_o = 0.001$. Colorless.

$KAg(CN)_2$ is trigonal with $c = 2.07$; no good cleavage. Uniaxial positive [12] with $N_o = 1.625$, $N_e = 1.63$, $N_e - N_o = 0.005$.

AgCN crystallizes in prisms [11] which are probably uniaxial; optic sign positive. $N_o = 1.685 \pm$, $N_e = 1.94$, $N_e - N_o = 0.255 \pm$.

$K_3Cu(CN)_4$ is trigonal in rhombohedral forms. Uniaxial negative with N = 1.5185 Li, 1.5215 Na, 1.5285 blue, $N_o - N_e$ = very weak.

AgI is hexagonal with $c = 0.82$. Crystals prismatic hemimorphic with perfect 0001 cleavage and flexible laminæ. Soft, sectile. G. = 5.6. Fuses at 527° C., giving iodine fumes and a silver globule. Soluble in NH_4OH. Uniaxial positive with [13] $N_o = 2.185$ C, 2.218 D,

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[9a] *Am. Jour. Sci.*, CCIV, 1922, p. 470.

[10] *Chem. Erde*, V, 1930, p. 529.

[11] Properties determined by H. E. Merwin—personal communication, Mar. 25, 1931.

[12] Indices measured by Bolland (*Sitz. Akad. Wiss. Wien.*, CXIX, 1910, p. 275) on "potassium silver cyanide" of unknown formula.

[13] H. E. Merwin: *Int. Crit. Tab.*, VII, 1930, p. 21.

2.328 F, $N_e = 2.229$ D, $N_e - N_o = 0.011$. May be slightly biaxial. Abnormal green interference colors. Color yellow to yellowish green. Inverts to the isometric phase at 146° C. Miscible with 10 mol. per cent or more of AgBr, retaining hexagonal symmetry.

NH_4HF_2 is orthorhombic with $a : b : c = 0.971 : 1 : 0.863$. Crystals pseudo-tetragonal and sometimes cubic in aspect; also basal tablets or long prismatic. G. = 1.5. Twinning of basal plates common in areas related to the external faces. The optic plane is 100; $X = c$. $(-)2V = 0°$ (Vigfusson[14]), 40° ± (Merwin[11a]), dispersion weak. $N_g = 1.394 \pm 0.003$, $N_m = 1.390 \pm 0.003$. $N_p = 1.385 \pm 0.003$, $N_g - N_p = 0.009 \pm 0.006$ (Vigfusson[14]); $N_g = 1.387 \pm$, $N_m = 1.385 \pm$, $N_p = 1.368 \pm N_g - N_p$ 20.019 (Merwin[11]).

. HYDROUS HALIDES AND CYANIDES OF MONOVALENT BASES

$KF \cdot 2H_2O$ is pseudohexagonal and probably monoclinic. Optic orientation unknown.[11] $(+)2V$ = very large, $N_g = 1.363 \pm$, $N_m = 1.352$, $N_p = 1.345 \pm$, $N_g - N_p = 0.018 \pm$. Colorless.

3. ANHYDROUS HALIDES AND CYANIDES OF DIVALENT BASES

CaF_2 is isometric with its atoms arranged as shown in Fig. 190. Crystals commonly cubic (see Fig. 191) or octahedral with perfect 111 cleavage and common twinning on 111 (see Fig. 192). H. = 4. G. = 3.18. Fusible with red flame color. Soluble in H_2SO_4 with evolution of HF. Isotropic with[15] N = 1.434; also weakly birefringent in some cases. Color often bright; yellow, blue, purple, green, red, brown; color not uniformly distributed and due to stain.

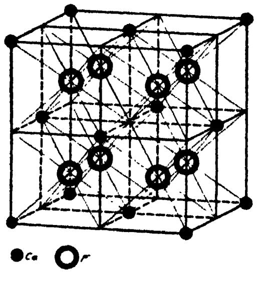

FIG. 190.—Space lattice of CaF_2.

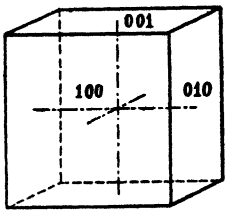

FIG. 191.—A crystal habit of CaF_2.

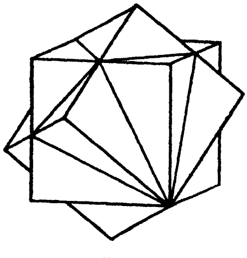

FIG. 192.—Penetration spinel twin in CaF_2.

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[14] V. A. Vigfusson: personal communication, Sept. 30 and Nov. 29, 1930.

[15] W. Wetzel: *Cent. Min.*, 1921, p. 444.

Made in several ways by reaction between HF and substances containing calcium. The natural substance, called *fluorite*, has remarkably constant properties due to absence of isomorphous (or other) variations in composition; it has[16] N = 1.4325 C, 1.43385 D, 1.4370 F, F − C = 0.0045; it is a rare constituent of igneous rocks and found in some veins.

CdF_2 is isometric[16a] with the CaF_2 space lattice and N = 1.56. Miscible in all proportions with CaF_2 with rectilinear variations of the refractive index.

SrF_2 is isometric[17] with the CaF_2 space lattice and G. = 4.24; N = 1.438. Also[17a] N = 1.442 ± 0.001 D. Miscible in all proportions[18] with CaF_2.

BaF_2 is isometric[17] with G. = 4.89 and N = 1.475. Also[17a] N = 1.4741 D.

$SrCl_2$ is isometric with G. = 3.08, F. = 872° C. and N[17a] = 1.6499 D.

$Sr_2Cl_2F_2$ is tetragonal[19] with good 001 cleavage and G. = 4.62. F. = 962° C. Uniaxial negative with $N_o = 1.651$, $N_e = 1.627$, $N_o - N_e = 0.024$.

$Ba_2Cl_2F_2$ is tetragonal[19] with good 001 cleavage and G. = 5.93. F. = 1008° C. Uniaxial negative with $N_o = 1.640$, $N_e = 1.633$, $N_o - N_e = 0.007$.

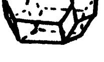

FIG. 193.—A crystal habit of Hg_2Cl_2

Hg_2Cl_2 is tetragonal with $c = 1.723$. Crystals, pyramids or basal plates (see Fig. 193) with distinct 100 cleavage. H. = 1–2. G. = 6.48. Volatile. Soluble in aqua regia. Uniaxial positive with $N_o = 1.9556$ Li, 1.9733 Na, 1.9909 Tl, $N_e = 2.6006$ Li, 2.6559 Na, 2.7129 Tl, $N_e - N_o = 0.6826$ Na. Color white or yellowish. The natural substance, called *calomel*, occurs rarely in the oxide zone of some ore deposits.

HgI_2 has two crystal phases; one phase is orthorhombic with $a : b : c = 0.649 : 1 : ?$ Crystals prismatic with 001; G. = 6.22. Color yellow. Forms isomorphous mixtures with $HgBr_2$ which have perfect 001 cleavage; the optic plane is 001 and *b* is the acute bisecting. Color yellow with weak pleochroism and $Z > X = Y$.

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[16] H. E. Merwin: *Am. Jour. Sci.*, CLXXXII, 1911, p. 429.

[16a] V. M. Goldschmidt: *Skr. Norsk. Vid. Akad.*, 1926, I, p. 84.

[17] F. Thilo: *Zeit. Kryst.*, LXV, 1927, p. 720; P. Wulff: *Zeit. Elektrochem.*, XXXIV, 1928, p. 611.

[17a] *Zeit. Kryst.*, LXXVII, 1931, p. 99.

[18] E. Rumpf: *Zeit. phys. Chem.*, VII, 1930, p. 148.

[19] H. Winter: *Inaug. Diss.* Leipzig, 1913. *Tables Ann. Const. Phys.*, IV, 1922, p. 1063, 1067.

The second crystal phase of HgI_2 is tetragonal with $c = 2.008$; crystals 001 tablets or pyramidal; twinning on 102. Perfect 001 cleavage. G. = 6.30. Uniaxial negative with[13] $N_o = 2.600$ C, 2.711 (600), 2.748 D, $N_e = 2.375$ C, 2.438 (600), 2.455 D, $N_o - N_e = 0.093$ D. Also biaxial with 2E reaching 30° and the optic plane parallel to 111 in 001. Color red with X = orange red, Z = blood red.

$ZnCl_2$ is uniaxial[11] and positive with $N_o = 1.687$, $N_e = 1.713$, $N_e - N_o = 0.026$. Colorless.

$Hg(CN)_2$ is tetragonal with $c = 0.459$; crystals short prismatic terminated by a sphenoid or rarely by a base. G. = 4.00. Imperfect 100 cleavage. Uniaxial negative with [20] $N_o = 1.645$, $N_e = 1.492$, $N_o - N_e$ 0.153.

$FeCl_2$ is hexagonal in basal plates. Uniaxial negative with $N_o = 1.567$, $N_o - N_e$ = rather weak (Larsen).[21] Color green to brown or yellow. Made by sublimation. Unstable. The natural substance, called *lawrencite*, is found rarely about volcanoes.

$MgCl_2$ is hexagonal in basal plates. Uniaxial negative with $N_o = 1.675$, $N_e = 1.59$, $N_o - N_e = 0.085$. Colorless. Made by ignition of $MgCl_2 \cdot 6H_2O$. Very deliquescent. The natural substance, called *chloromagnesite*, is found as a rarity about volcanoes.

$CaCl_2$ is probably orthorhombic[22] and pseudotetragonal. G. = 2.2. Very deliquescent. It has very perfect prismatic cleavage and lamellar twinning on 110 and 1$\bar{1}$0 like that of microcline. (+) 2V = moderate, $N_g = 1.613$, $N_m = 1.605$, $N_p = 1.600$, $N_g - N_p = 0.013$. The substance may react with index liquids containing turpentine, etc., to an isotropic substance with N = 1.52; it does not react with α-monobromnaphthalene nor with paraffin oil; natural $CaCl_2$, called *hydrophilite* is found about volcanoes.

$BaCl_2$ is biaxial with[17a] $N_g = 1.74196$, $N_m = 1.73611$, $N_p = 1.73024$, $N_g - N_p = 0.0117$. Therefore (+) 2V = 90° very nearly.

$HgCl_2$ is orthorhombic with $a : b : c = 0.725 : 1 : 1.070$. Crystals brachydomatic, short prismatic (with 110, 010, and 001) or thin basal tablets, with perfect 011 and poor 001 cleavages. G. = 6.22. The optic plane is 100; $X = c$. (−) 2V = 85° (calc.), N_g[13] = 1.965,

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[20] E. M. Chamot and C. W. Mason: *Chem. Microscopy*, I, 1930, p. 330.

[21] Index too low as compared with $MgCl^2$; perhaps hydrated ?—A. N. W.

[22] C. B. Slawson: *Am. Mineral.*, XIV, 1929, p. 160. But Wulff (*Zeit. Kryst.*, LXXVII, 1931, p. 84) gives $N_g = 1.542 \pm .002$, N_m = ?, $N_p = 1.531 \pm .002$, $N_g - N_p = 0.017$ for $CaCl_2$.

$N_m = 1.850$ C, 1.859 D, 1.882 F, $N_p = 1.725$, $N_g - N_p = 0.24$. Formed from solution in alcohol or from sublimation.

$PbCl_2$ is orthorhombic with $a : b : c = 0.595 : 1 : 1.187$; crystals 010 or 001 tablets or columnar parallel to a, with perfect 001 cleavage. G. = 5.84. F. = 1. Soluble in hot water. The optic plane is 010; $Z = c$. (+) $2V = 66° 12'$ Na, $N_g = 2.260$ Na, $N_m = 2.192$ Li, 2.217 Na, $N_p = 2.179$ Li, 2.199 Na, $N_g - N_p = 0.061$ Na. Colorless, greenish or yellowish in mass. Made from solution. The natural substance, called *cotunnite*, is found rarely about volcanoes.

4. HYDROUS HALIDES AND CYANIDES OF DIVALENT BASES

$MgPt(CN)_4 \cdot 7H_2O$ is tetragonal with $c = 0.61$, and perfect 001 cleavage. Uniaxial positive[23] with $N_o = 1.5546$ B, 1.5585 C, 1.5608 D, 1.57 E, $N_e = 1.905$ C, 1.91 D, $N_e - N_o = 0.35$ D. Color carmine red with X more, and Z less, bluish. Surface color on 100 metallic greenish. Strongly pleochroic phosphorescence.

$CaCl_2 \cdot 6H_2O$ is trigonal with $c = 0.505$. Crystals prismatic with perfect basal and prismatic cleavages. G. = 1.68. Very deliquescent. Uniaxial negative with $N_o = 1.417$ Na, $N_e = 1.393$, $N_o - N_e = 0.024$. Colorless. Formed from H_2O solution in a vacuum.

$SrCl_2 \cdot 6H_2O$ is trigonal with $c = 0.515$. Crystals prismatic with perfect basal cleavage. G. = 1.96. Uniaxial negative with $N_o = 1.5327$ Li, 1.5364 Na, $N_e = 1.4836$ Li, 1.4866 Na, $N_o - N_e = 0.0498$ Na. Also[23a] $N_o = 1.5356$, $N_e = 1.4857$, $N_o - N_e = 0.0499$ D. Colorless.

$CaMg_2Cl_6 \cdot 12H_2O$ is trigonal[24] with $c = 1.76$. Perfect $10\bar{1}1$ cleavage. H. = 2. G. = 1.67. Deliquescent. Uniaxial negative with $N_o = 1.520$, $N_e = 1.512$, $N_o - N_e = 0.008$. Color pale yellow. Made from solution. The natural substance, called *tachyhydrite*, is found at Stassfurt, etc.

$CoF_2 \cdot 5HF \cdot 6H_2O$ is trigonal[25] with $c = 1.04$. Crystals flattened prisms with prismatic cleavage. G. = 2.04. Uniaxial positive with $N_o = 1.382$ C, 1.384 D, 1.390 G′, $N_e = 1.397$ C, 1.399 D, 1.406 + G′, $N_e - N_o = 0.015$ D. Color orange red.

$NiF_6 \cdot 5HF \cdot 6H_2O$ is trigonal[25] with $c = 2.01$. Crystals flattened prisms with prismatic cleavage. Uniaxial positive with N_o = 1.390 C, 1.392 D, 1.395 F, N_e = 1.406 C, 1.408 D, 1.410 F, $N_e - N_o$ = 0.016. Color blue-green.

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[23] P. Gaubert: *Bull. Soc. Fr. Min.*, XL, 1917, p. 177.

[23a] P. Wulff: *Zeit. Kryst.*, LXXVII, 1931, p. 100.

[24] H. Jung: *Cent. Min.*, 1926, A, p. 273.

[25] *Jour. Am. Chem. Soc.*, XLII, 1920, p. 2432. H. E. Merwin: *Int. Crit. Tab.*, VII, 1930, p. 22.

$CuCl_2 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.918 : 1 : 0.463$. Crystals prismatic with nearly rectangular cruciform twinning on 021, and perfect 001 and 110 cleavages. G. = 2.47. The optic plane[26] is 001; $Z = a$. (+) $2V = 80° 40'$, $\rho < v$. $N_g = 1.742$, $N_m = 1.684$, $N_p = 1.644$, $N_g - N_p = 0.098$. Color emerald green with weak pleochroism. Formed from acid solution.

$Cd_2MgCl_6 \cdot 12H_2O$ is orthorhombic with $a : b : c = 0.913 : 1 : 0.304$. Crystals prismatic (with 010, 110, 210, 100 and 111 faces) with probable 100 and 010 cleavages. Deliquescent. The optic plane is 100; $Z = c$. (+) 2V = very large, $\rho < v$, weak. N_g = 1.5728 red, 1.5769 Na, N_m = 1.5268 red, 1.5331 Na, $N_p = 1.49 \pm$, $N_g - N_p = 0.08 \mp$.

$CaPt(CN)_4 \cdot 5H_2O$ is orthorhombic with $a : b : c = 0.899 : 1 : 0.349$. Crystals prismatic (120, 100 and 010) with perfect 100 cleavage. The optic plane is 010; $X = c$. For 656 mμ (+) $2E = 106° 42'$, $2V = 58° 3'$, $N_g = 1.714$, $N_m = 1.633$, $N_p = 1.617$, $N_g - N_p = 0.097$. For 588 mμ (+) $2E = 84° 17'$, $2V = 48° 10'$, $N_g = 1.767$, $N_m = 1.644$, $N_p = 1.623$, $N_g - N_p = 0.144$. For 502 mμ (+) $2E = 58° 13'$, $2V = 34° 11'$, $N_g = 1.949$, $N_m = 1.655$, $N_p = 1.633$, $N_g - N_p = 0.316$. For 486 mμ (+) $2V = 30° 23'$, $N_g = 2.030 \pm$, $N_m = 1.658$, $N_p = 1.636$, $N_g - N_p = 0.394$. Color green without distinct pleochroism; fluorescent.

$MgPt(CN)_4 \cdot C_3H_8O_3 \cdot 5H_2O$ is monoclinic with $a : b : c = 0.965 : 1 : 0.492$, $\beta = 85° 56'$. Crystals short prismatic, vertically striated with distinct 001 cleavage. The optic plane is normal to 010 for Li, and parallel to 010 for Na and Tl light. $X \wedge c = 24°$ for A, 30° for D (Na), 36° for E and 68° for G light. (−) $2E = 17° 25'$ Li, 28° 8′ Na, 55° 40′ Tl, $2V = 17° 39'$ Na, 34° 18′ Tl, 60° (blue); N_m = 1.584 Na, 1.589 Tl, $N_g - N_p$ = ? Formed by evaporation of a glycerine solution of magnesium platinum cyanide.

$SrPt(CN)_4 \cdot 5H_2O$ is monoclinic[27] with $a : b : c = 0.685 : 1 : 0.466$, $\beta = 85° 11'$. It has distinct 001 cleavage; lamellar twinning on 100, giving pseudorhombic appearance. The optic plane is 010; $X \wedge c$ = + 18° Li, + 19.5° Na, + 27° Tl, + 41° (blue). (−) $2E = 35° \pm$, $2V = 20° \pm$, N'_g = 1.6264 C, 1.6331 He yellow, 1.6489 He green, N'_p = 1.5638 C, 1.5800 He yellow, 1.6152 He green, $N'_g - N'_p$ = 0.0626 C. Colorless, with blue fluorescence.

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[26] Measured by A. E. Merwin—personal communication, Mar. 25, 1931.

[27] *Zeit. Kryst.*, XLIX, 1911, p. 118.

$BaPt(CN)_4 \cdot 4H_2O$ is monoclinic with $a : b : c = 0.868 : 1 : 0.479$, $\beta = 76° 18'$. Crystal prismatic or 010 tablets. G = 3.05. The optic plane is 010; $Z \wedge c = -1° 20'$. (+) 2E = 35° 13′ red, 31° 16′ Na, 27° 16′ green, $\rho > v$; 2V = 18° Na. N_g[28] = 1.8074 Li, 1.8982 Na, 2.2540 green, N_m = 1.677 Na (calc.), N_p = 1.6645 Li, 1.6706 Na, 1.6834 green, $N_g - N_p$ = 0.2276 Na. Color yellow with Z darkest. Surface color on 110 blue or violet; fluorescence on 011 emerald green.

$CdCl_2 \cdot 2.5H_2O$ is monoclinic with $a : b : c = 1.177 : 1 : 1.112$, $\beta = 84° 12'$. Crystals varied with distinct 001 cleavage. The optic plane is 010; $Z \wedge c = +1° 40'$. (+) 2V = 56° 42′ red, 56° 27′ Na, $\rho > v$ weak. N_m = 1.6428 red, 1.6513 Na, $N_g - N_p$ = ? Colorless. Formed from H_2O solution. Another phase is also monoclinic.

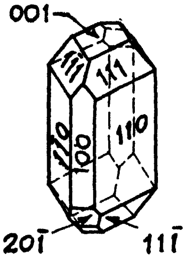

FIG. 194.—A crystal habit of $BaBr_2 \cdot 2H_2O$. (After Mügge).

$BaCl_2 \cdot 2H_2O$ is monoclinic with $a : b : c = 0.618 : 1 : 0.655$, $\beta = 88° 55'$. Crystals octagonal tablets parallel to 010, twinned on 001 or 100. No good cleavage. G. = 3.09. The optic plane is 010; $Z \wedge c = 8°$; (+) 2V = 84° 50′ red, 83° 46′ Na, N_g = 1.660 Na, N_m = 1.641 red, 1.646 Na, N_p = 1.635, $N_g - N_p$ = 0.025. Also[17a] N_g = 1.6583, N_m = 1.6419, N_p = 1.6291, $N_g - N_p$ = 0.0292. Colorless. Formed from a weak HCl solution.

$BaBr_2 \cdot 2H_2O$ is monoclinic with $a : b : c = 1.45 : 1 : 1.16$, $\beta = 66° 30'$. Crystals short prismatic (see Fig. 194) or 001 tablets or columnar by elongation of the form 11$\bar{1}$. Twinning on 100 or 001. Poor 100, 10$\bar{1}$ or 001 cleavages. G. = 3.69. The optic plane is 010; $Z \wedge c = +89° 35'$ Na. (+) 2V = 83° 30′ Li, 83° 49′ Na, 84° 8′ Tl. N_g = 1.7382 C, 1.7441 D, 1.7588 F, N_m = 1.7205 C, 1.7266 D, 1.7418 F, N_p = 1.7067 C, 1.7129 D, 1.7282 F, $N_g - N_p$ = 0.0312 D. Colorless. Formed from H_2O solution; crystals easily deformed.

$SrCl_2 \cdot 2H_2O$ is probably monoclinic with[23a] G. = 2.67 and $N_g = 1.6172 \pm .0001$. $N_m = 1.5948 \pm .0004$, $N_p = 1.5942 \pm .0002$, $N_g - N_p$ = 0.0230. Therefore (+) 2V = small.

$MnCl_2 \cdot 4H_2O$ (α-phase) is monoclinic with $a : b : c = 1.141 : 1 : 1.641$, $\beta = 69° 14'$. Crystals 001 tablets modified by the 111 pyramid;

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[28] H. Baumhauer: *Zeit. Kryst.*, XLIV, 1908, p. 38.

also prismatic with negative[29] elongation. Twinning common on recrystallization. (+) 2V = 78° ± 3° (calc.) with $\rho < v$ moderate. $N_g = 1.607 \pm 0.003$, $N_m = 1.575$, $N_p = 1.555$, $N_g - N_p = 0.052$. Obtained by crystallization from a saturated solution at 0°–6° C.

$NiCl_2 \cdot 6H_2O$ is monoclinic with $a : b : c = 1.468 : 1 : 0.943$, $\beta = 57° 30'$. Crystals 100 tablets with 110 and 001 or 110 twins, with perfect 001 cleavage. The optic plane is 010; $X \wedge c = +8° \pm$. (+) 2V = very large. $N_g = 1.61$,[30] $N_m = ?$, $N_p = 1.535$, $N_g - N_p = 0.075$.

$CuF_2 \cdot 5HF \cdot 6H_2O$ is monoclinic[25] with three cleavages. G. = 2.41. Loses water easily. Extinction parallel to one cleavage and much inclined to another. Negative elongation. (−) 2V = 32°, $N_g = 1.444$ $N_m = 1.440$, $N_p = 1.395$, $N_g - N_p = 0.049$. Color (greenish) blue with $X < Y = Z$.

$CoCl_2 \cdot 2H_2O$ is probably triclinic;[31] crystals lath-shaped and nearly rectangular, elongated parallel to *a* and lamellar parallel to 001, usually limited by 001, 010 and 100; distinct 010 and 001 cleavages. G. = 2.42. Crystals plastic. Extinction on laths always inclined at an acute angle. Biaxial and negative with N_g distinctly greater than 1.67, N_m slightly less than 1.671 and N_p slightly less than 1.625. Color deep bluish violet with X = blue, Y = pale carmine, Z = distinct carmine in plates 10–50 μ in thickness. Formed from $CoCl_2 \cdot 6H_2O$ by drying in a desiccator at 50° C. Hydrates easily.

$Ca_2Fe(CN)_6 \cdot 12H_2O$ is triclinic with $a : b : c = 1.054 : 1 : 0.841$, $\alpha = 97° 9'$, $\beta = 89° 57'$, $\gamma = 107° 24'$. Crystals complex with perfect 100 cleavage. The optic plane is nearly normal to 001; an optic axis nearly normal to 010; a normal to 010 makes an angle of 16° 18′ (Na) with Z and 77° 10′ with X; a normal to 001 makes an angle of 87° 56′ with Z and 16° 28′ with X; a normal to 100 makes an angle of 59° 31′ with Z and 71° 21′ with X. (+) 2V = 85° 12′ Na, $\rho > v$. $N_g = 1.5902$ Li, 1.5961 Na, 1.6017 Tl, $N_m = 1.5764$ Li, 1.5818 Na, 1.5871 Tl, $N_p = 1.5646$ Li, 1.5700 Na, 1.5753 Tl, $N_g - N_p = 0.0261$ Na. Color yellow.

$BaCdCl_4 \cdot 4H_2O$ is triclinic with $a : b : c = 0.855 : 1 : 0.513$, $\alpha = 92° 35'$, $\beta = 106° 18'$, $\gamma = 88° 26'$. Crystals short prismatic with two types of lamellar twinning much like plagioclase. Perfect 110 and $1\bar{1}0$ cleavages. G. = 2.97. Axis X nearly normal to 110; optic plane nearly vertical with extinction of 11° on 110, 6° on 010, 2.5° on 100 and 4.5° on $1\bar{1}0$. $(-)\ 2V = 61° 1'$, $\rho < v$. $N_m = 1.638$ red, 1.651 Na, 1.664 blue, $N_g - N_p$ = not very strong.

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[29] Optic properties measured by Dr. V. A. Vigfusson—personal communication, Dec. 18, 1930.

[30] Indices measured by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) on "nickel chloride" of unknown formula.

[31] A. Neuhaus: *Chem. Erde*, V, 1930, p. 554.

$BaCdBr_4 \cdot 4H_2O$ is isomorphous with $BaCdCl_4 \cdot 4H_2O$ with the same cleavages and twinning. G. = 3.69. Optic orientation only slightly different with extinction angles differing only 1° or 2°. $(-)\ 2V = 70° 13'$, $\rho < v$. $N_m = 1.693$ red, 1.702 Na, $N_g - N_p$ = ?

5. HALIDES OF TRIVALENT BASES

$AlCl_3 \cdot 6H_2O$ is trigonal with $c = 0.534$. Deliquescent in air. Uniaxial negative[32] with $N_o = 1.560$, $N_o - N_\epsilon = 0.053 \therefore N_p = 1.507$. Colorless. Made from H_2O solution.

AsI^3 is trigonal with $c = 2.998$; crystals usually hexagonal basal plates with perfect 0001 cleavage. Uniaxial negative[11] with $N_o = 2.59 \pm C$, $N_\epsilon = 2.23 \pm C$, $N_o - N_\epsilon = 0.36 \pm$. Color deep red.

SbI_3 crystallizes in three different phases; the low temperature trigonal crystals are usually in hexagonal basal plates with G. = 4.85. Uniaxial negative[11] with $N_o = 2.78 \pm$ Li, $N_\epsilon = 2.36 \pm$, $N_o - N_\epsilon = 0.42 \pm$. Color deep ruby red.

$SbBr_3$ is orthorhombic[33] with $a : b : c = 0.781 : 1 : 1.165$. Crystals 001 tablets with good 010 cleavage. G. = 4.15. Very deliquescent. Optic orientation unknown. N = very high, considerably above 1.74. Optically negative. $N_g - N_p$ = very strong. Colorless with luster and dispersion like that of diamond.

6. HALIDES OF TETRAVALENT BASES

$GeBr_4$ is isometric[34] in octahedral crystals with G. = 3.13 (as a liquid at 29°). F. = 26° C. Isotropic with N = 1.6269.

SnI_4 is isometric and octahedral with G. = 4.70. Isotropic[11] with N = 2.063 ± Li, 2.106 ± Na, 2.161 ± Tl. Color red.

$SiCl_4$ is isotropic[35] with N = 1.412 C. G. = 1.483 as a liquid. F. = −70° C.

$SiBr_4$ is isotropic[35] with N = 1.579 F. G. = 2.812 at 0° C. F. = 5° C.

[32] Dennis and Gill: *Zeit. anorg. Chem.*, IX, p. 340; G. *Takahashi, et al.*: *Jour. Geol. Soc. Tokyo*, XXXV, 1928, p. 439.

[33] C. B. Slawson: *Am. Mineral*, VII, 1922, p. 173.

[34] L. M. Dennis and F. E. Hance: *Chem. News*, CXXIV, 1922, p. 67.

[35] *Int. Crit. Tables*, I, 1926, p. 112.

7. ANHYDROUS HALIDES AND CYANIDES OF DIVALENT AND MONOVALENT BASES

$K_2Zn(CN)_4$ is isometric[36] in octahedrons with G. = 1.673 and N = 1.406 Li, 1.413 Na, 1.417 Tl. Colorless.

$K_2Cd(CN)_4$ is isometric[36] and octahedral with G. = 1.824 and N = 1.415 Li, 1.4213 Na, 1.425 Tl.

$K_2Hg(CN)_4$ is isometric[36] and octahedral with G. = 2.438 and N = 1.451 Li, 1.458 Na, 1.461 Tl.

$K_2Zn(CN)_4$ and **$K_2Cd(CN)_4$** form mix-crystals[36] in which for 20.76 per cent $K_2Zn(CN)_4$, G. = 1.789 and N = 1.4191 Na at 25° C.; for 39.41 per cent $K_2Zn(CN)_4$, G. = 1.768, N = 1.4175 Na; for 60.02 per cent $K_2Zn(CN)_4$, G. = 1.744, N = 1.416; for 81.13 per cent $K_2Zn(CN)_4$, G. = 1.682, N = 1.4141.

$K_2Zn(CN)_4$ and **$K_2Hg(CN)_4$** form mix-crystals[36] in which for 53.21 per cent $K_2Zn(CN)_4$, G. = 1.962, N = 1.452 Na at 25° C.; for 65.42 per cent $K_2Zn(CN)_4$, G. = 1.883, N = 1.447; for 76.08 $K_2Zn(CN)_4$, G. = 1.801, N = 1.443; for 88.36 per cent $K_2Zn(CN)_4$, G. = 1.738, N = 1.436.

$K_2Cd(CN)_4$ and **$K_2Hg(CN)_4$** form mix-crystals[36] in which for 22.00 per cent $K_2Cd(CN)_4$, G. = 2.261 and N = 1.451 Na at 25° C.; for 39.40 per cent $K_2Cd(CN)_4$, G. = 2.151 and N = 1.441; for 61.29 per cent $K_2Cd(CN)_4$, G. = 2.005 and N = 1.435; for 82.10 per cent $K_2Cd(CN)_4$, G. = 1.927 and N = 1.428.

$(NH_4)_2FeCl_4$ is isometric[37] and isotropic with N = 1.6439 D.

K_2PtCl_4 is tetragonal with $c = 0.416$. Crystals prismatic with G. = 3.3. Uniaxial positive[38] with $N_o = 1.64$, $N_e = 1.67$, $N_e - N_o = 0.03$. Color dark red-brown; microscopically clear violet with O brighter than E and slightly greenish.

K_4CdCl_6 is trigonal with $c = 0.607$; crystals rhombohedral with perfect rhombohedral cleavage. Twinning common. Uniaxial positive with $N_o = 1.5841$ B, 1.5906 D, 1,5965 E, 1.6208 H, $N_e = 1.5842$ B, 1.5907 D, 1.5966 E, 1.6210 H, $N_e - N_o = 0.0001$ D.

$(NH_4)_4CdCl_6$ is trigonal with $c = 0.637$. Crystals rhombohedral. G. = 2.01. Uniaxial positive with $N_o = 1.5958$ B, 1.6038 D, 1.6110 E,

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[36] E. Carozzi: *Gazz. Chim. Ital.*, LVI, 1926, p. 180. *Tables Ann. Const. Phys.*, VII, 2, 1930, p. 1489.

[36] *Int. Crit. Tables*, I, 1926, p. 112.

[37] Landolt-Börnstein: *Tabellen*, 1924.

[38] Optic data by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) on "potassium platinum chloride" of unknown formula.

1.6414 H, N_e = 1.5961 B, 1.6042 D, 1.6114 E, 1.6418 H, $N_e - N_o$ = 0.0004 D.

$CsHgCl_3$ is isometric and orthorhombic. Crystals octahedral with no distinct cleavage, but weakly birefringent with extinction parallel to the diagonals of the cube. Rhombic crystals have a similar habit, with $a : b : c = 0.577 : 1 : 0.409$. Extremely weak birefringence with N = 1.779 Li, 1.791 Na. Formed from H_2O solution.

$(NH_4)_2ZnCl_4$ is orthorhombic with $a : b : c = 0.722 : 1 : 0.570$. Crystals 010 lamellæ. G. = 1.88. The optic plane is 001; Z = a. (+) 2V = 53° 48′, $\rho > v$ weak. N_m = 1.5055 D, $N_g - N_p$ = ? Colorless. Formed from H_2O solution with NH_4Cl in excess.

$(NH_4)_3ZnCl_5$ is orthorhombic with $a : b : c = 0.782 : 1 : 0.692$. Crystals vertical columns or 010 tablets or equant. G. = 1.81. The optic plane is 001; Z = a. (+) 2V = 46° 10′, $\rho > v$ weak. N_m = 1.538, $N_g - N_p$ = ? Colorless. Formed from H_2O solution.

8. HYDROUS HALIDES AND CYANIDES OF DIVALENT AND MONOVALENT BASES

$K_2CuCl_4 \cdot 2H_2O$ is tetragonal with $c = 0.752$; crystals pyramidal, prismatic or pseudododecahedral; twinning on 111. G. = 2.41. Uniaxial negative with N_o = 1.6438 (623), 1.647 D (interpol.), 1.6485 (578), 1.6636 (492), N_e = 1.6097 (623), 1.6133 (578), 1.6235 (492), $N_o - N_e$ = 0.0352 (578) (Ehringhaus [39]). Color green; pleochroic with X = sky blue, Z = grass green and X < Z. Also biaxial and probably orthorhombic with twinning on 110 in four sectors in which the optic plane is parallel to the diagonal (in 001) and 2H = 25°. Recently found at Vesuvius [40] and named *mitscherlichite.*

$(NH_4)_2CuCl_4 \cdot 2H_2O$ is tetragonal with $c = 0.742$; crystals pyramidal or pseudododecahedral with 111 and 100; twinning on 111. G. = 2.06. Uniaxial negative [20] with N_o = 1.670, N_e = 1.645, $N_o - N_e$ = 0.025. Also biaxial with 2H = 16° or less, twinned on 110.

$(NH_4)_4Fe(CN)_6 \cdot 2NH_4Cl \cdot 3H_2O$ is trigonal with $c = 1.032$; crystals rhombohedral with no distinct cleavage. G. = 1.49. Uniaxial negative with N_o = 1.6067 Li, 1.6198 Na, 1.6241 Tl, N_e = 1.5881 Li, 1.5922 Na, 1.5964 Tl, $N_o - N_e$ = 0.0276 Na. Color yellow.

$K_2HgCl_4 \cdot H_2O$ is orthorhombic with $a : b : c = 0.707 : 1 : 0.766$. Crystals prismatic or tabular parallel to 110. The optic plane is 001;

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[39] *N.J. Min. Bl. Bd.* XLI, 1917, p. 342.

[40] *Min. Abst.*, IV, 1929, p. 14.

X = *a*. (−) 2V = 78° 25′, $\rho > v$ strong. N_g = 1.699 Na, N_m = 1.678, N_p = 1.648, $N_g - N_p$ = 0.051.

$LiKPt(CN)_4 \cdot 3H_2O$ is orthorhombic with $a : b : c$ = 0.715 : 1 : 0.444. Crystals prismatic with no good cleavage. The optic plane is 100; Z = *c*. (+) 2V = 19°, $\rho > v$ distinct. For 656 mμ N_g = 2.0405, N_m = 1.6217, N_p = 1.6183, $N_g - N_p$ = 0.4217. For 588 mμ N_g = 2.2916, N_m = 1.6278, N_p = 1.6237, $N_g - N_p$ = 0.6679. Color red; pleochroic with X = Y = orange yellow, Z = red.

$LiRbPt(CN)_4 \cdot 3H_2O$ is orthorhombic with $a : b : c$ = 0.715 : 1 : 0.448. Crystals prismatic. The optic plane is 100; Z = *c*. (+) 2V = 12° 40′, $\rho > v$ distinct. For 656 mμ N_g = 1.827, N_m = 1.6176, N_p = 1.6153; for 588 mμ N_g = 1.9310, N_m = 1.6233, N_p = 1.6204, $N_g - N_p$ = 0.3106. Color yellow; fluorescence green; pleochroic with X = Y = light yellow, Z = gold yellow.

$KMgBr_3 \cdot 6H_2O$ is orthorhombic pseudotetragonal without cleavage; twinning on 110. H. = 2. The optic plane is 001; Z = *b*. (+) 2V = 87°, N_m = 1.535, $N_g - N_p$ = very strong. Colorless. Destroyed by heat at about 100° C. Crystal solutions of this salt and *carnallite* (15 to 85 per cent) are tetragonal, uniaxial positive, N_o = 1.52 ±, $N_o - N_e$ = very weak like leucite, increasing with increase of chlorine.

$K_2Pt(CN)_4 \cdot 3H_2O$ is orthorhombic with $a : b : c$ = 0.879 : 1 : 0.274. Crystals short prismatic without cleavage. The optic plane is 100; Z = *c*. (+) 2E = 78° red, 40° blue. N'_g = 1.62,[41] N_m = ?, N'_p = 1.615, $N'_g - N'_p$ = 0.005. Colored and fluorescent.

$Rb_2Pt(CN)_4 \cdot 3H_2O$ (?) is monoclinic[42] with $a : b : c$ = 0.931 : 1 : 0.533, β = 80° 12′. Crystals 100 tablets or prismatic. The optic plane is normal to 010; Z nearly = *c*. (+) 2V = moderate with distinct horizontal dispersion. N'_g = 1.656 He red, 1.662 C, 1.696 He yellow, 1.816 He green, N_m = 1.62 ±, N'_p = 1.6056 He red, 1.6072 C, 1.6111 He yellow, $N'_g - N'_p$ = 0.054 C, 0.085 He yellow. Color pale green, weakly fluorescent in blue. Alters easily to colorless state.

$K_4Os(CN)_6 \cdot 3H_2O$ is monoclinic with $a : b : c$ = 0.393 : 1 : 0.394, β = 89° 54′. Crystals 010 plates with perfect 010 cleavage. The optic plane is normal to 010; X ∧ *c* = + 30° 10′. (−) 2V = 47° 0′, N_m = 1.6071, $N_g - N_p$ = ? Colorless.

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[41] Indices measured by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) on "potassium platinum cyanide" of unknown formula.

[42] *Zeit. Kryst.*, XLIX, 1911, p. 119. Bolland gives (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) for "rubidium platinum cyanide": N_g = 1.95 +, N_m = 1.71, N_p = 1.56, $N_g - N_p$ = 0.39 +.

$K_4Ru(CN)_6 \cdot 3H_2O$ is monoclinic with $a : b : c = 0.394 : 1 : 0.395$, $\beta = 89° 54'$. Crystals 010 plates (with 110 and 011) with perfect 010 cleavage. The optic plane is normal to 010; $X \wedge c = +32° 10'$. $(-) 2V = 54° 0'$, $N_m = 1.5837$ Na, $N_g - N_p = ?$ Colorless.

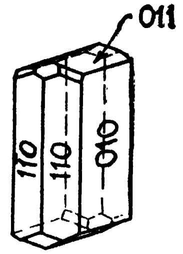

FIG. 195.—Pseudotetragonal habit of potassium ferrocyanide. (After Groth).

$K_4Fe(CN)_6 \cdot 3H_2O$ is monoclinic with $a : b : c = 0.3936 : 1 : 0.3943$, $\beta = 89° 58'$; crystals prismatic, pseudotetragonal with 010 (= pseudotetragonal base), 110 and 011; see Fig. 195. Twinning on 100 or 001; 010 may be the composition face of twins. Perfect 010 cleavage. G. = 1.9 ±. The optic plane is normal to 010; $X \wedge c = +31° 50'$. $(-) 2V = 78° 10'$ Na, $\rho > v$ very weak. $N_m = 1.5772$, $N_g - N_p = (?)$[43] Color yellow.

$Li_2K_2Fe(CN)_6 \cdot 3H_2O$ is monoclinic with $a : b : c = 0.962 : 1 : 0.747$, $\beta = 83° 52'$; crystals tabular parallel to 100 and vertically elongated. Twinning on 100. The optic plane is 010; $X \wedge c = -44°$. $(-) 2V = 66° 31'$ Li, $65° 56'$ Na, $65° 22'$ Tl, $\rho > v$, weak. $N_g = 1.6316$ Na, $N_m = 1.5947$ Li, 1.6007 Na, 1.6066 Tl, $N_p = 1.5883$ Na, $N_g - N_p = 0.0433$. (Indices make this positive.)

$Na_4Fe(CN)_6 \cdot 12H_2O$? is monoclinic with $a : b : c = 0.852 : 1 : 0.787$, $\beta = 82° 26'$; crystals prismatic with 010, 110, 011, 100, 101; indistinct 110 cleavage. G. = 1.46. The optic plane is 010; $Z \wedge c = +74°$. $(+) 2V = 81° 25'$ Na, $\rho > v$, weak. $N_g = 1.5436$ Na, $N_m = 1.528$ red, 1.5295 Na, 1.536 green, $N_p = 1.5193$ Na, $N_g - N_p = 0.0243$. Color yellow with Y > X > Z. Formed from H_2O solution.

$NaKPt(CN)_4 \cdot 3H_2O$ [44] is monoclinic[44] with $a : b : c = 0.852 : 1 : 0.472$, $\beta = 84° 52'$. Crystals prismatic with 110, 011, 010. The optic plane is nearly normal to the edge of 011. $(+) 2V$ = very small. $N_g = 1.90$ ±, $N_m = 1.61$ ±, $N_p = 1.6088$ D, $N_g - N_p = 0.29$ ±. Color orange.

$Cs_2MnCl_4 \cdot 2H_2O$ is triclinic (?) in long plates formed of 001 and 100 at an angle of 84° 33'; good 001 cleavage. Extinction[45] on plates at 45° to edge. $N'_g = 1.65$, $N_m = ?$, $N'_p = 1.64$, $N'_g - N'_p = 0.01$.

$Na_2Pt(CN)_4 \cdot 3H_2O$ is triclinic[46] and pseudohexagonal, with $a : b : c = 1.701 : 1 : 0.809$. $\alpha = 94° 57'$, $\beta = 92° 18'$, $\gamma = 89° 1'$. Crystals prismatic, always twinned on 100; also twinning on 110 and on axis *c*. Perfect 001 cleavage. Extinction from trace of optic plane in 001 is in 100 $\wedge$ 1$\bar{1}$0 at 41° to 001 : 100 edge in Na light. The same extinction angle in red is 26° greater than in blue light. (−) 2V = small, $\rho > v$, strong, with strong crossed dispersion. $N_g = 1.61$, $N_m = 1.60 \pm$, $N_p = 1.53$, $N_g - N_p = 0.08$. Dispersion for N'_m, He green − He red = 0.0194. Colorless.

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[43] Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) gives $N_g - N_p = 0.005$.

[44] P. Gaubert: *Bull. Soc. Fr. Min.*, XL, 1917, p. 181. Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) gives $N_g = 1.95 +$, $N_g - N_p = 0.335 +$.

[45] Optic data by Bolland on "cæsium manganese chloride" of unknown formula.

[46] *Zeit. Kryst.*, XLIX, 1911, p. 113.

9. ANHYDROUS HALIDES AND CYANIDES OF TRIVALENT AND MONOVALENT BASES

$(NH_4)_3ScF_6$ is tetragonal[47] with $c = 1.02$. G. = 1.80. Uniaxial negative with N_o less than 1.47, $N_o - N_e$ = weak.

$Cs_3Tl_2Cl_9$ is hexagonal with $c = 0.826$. Uniaxial negative with $N_o = 1.772$ Li, 1.784 Na, 1.792 Tl, $N_e = 1.762$ Li, 1.774 Na, 1.786 Tl, $N_o - N_e = 0.010$ Na.

$(NH_4)_2MnF_5$ is orthorhombic[47] with $a : b : c = 0.576 : 1 : 0.742$. G. = 2.37. 010 cleavage. The optic plane is 010; X = *c*. (−) 2V = ?, $N_g = 1.50$, $N_m = ?$, $N_p = 1.46$, $N_g - N_p = 0.04$.

KBF_4 is orthorhombic[48] with $a : b : c = 0.790 : 1 : 1.283$. Crystals 001 tablets elongated parallel to *b* (also *a*). G. = 2.505. The optic plane is 010 (100?), X = *c*. (−) 2V = moderate, $N_g = 1.3247$ Na, 1.3255 (577), $N_m = 1.3236$ (677), 1.3245 Na, 1.3253 (577), $N_p = 1.3231$ (677), 1.3239 Na, 1.3248 (577), $N_g - N_p = 0.0008$ Na. Colorless.

$CsBF_4$ is similar to KBF_4 with G. = 3.305 and N = 1.36 Na.

$CsCeCl_4$[49] is monoclinic (?) extinguishing at 11° from elongation. It is biaxial with N = 1.58, and $N_g - N_p$ = weak. Colorless.

$K_3Cr(CN)_6$ is monoclinic with $a : b : c = 1.287 : 1 : 0.805$, $\beta = 89° 57'$. Crystals prismatic; lamellar twinning on 100; 100 cleavage. The optic plane is 010; $Z \wedge c = 0° \pm$. (+) 2E = 72° 23′ Li, 73° 32′ Na, 74° 2′ Tl, 2V = 46°. $N_g = 1.5324$ Li, 1.5373 Na, 1.5423 Tl, $N_m = 1.5198$ Li, 1.5244 Na, 1.5292 Tl, $N_p = 1.5176$ Li, 1.5221 Na, 1.5268 Tl, $N_g - N_p = 0.0151$ Na. Color clear yellow.

$K_3Mn(CN)_6$ is monoclinic with $a : b : c = 1.289 : 1 : 0.801$, $\beta = 89° 53'$. Crystals prismatic; twinning on 100; 100 cleavage. The optic plane is 010; $Z \wedge c = 0° \pm$. (+) 2E = 70° 31′ Li, 74° 4′ Na. 2V = 43°. $N_g = 1.5710$ Li, $N_m = 1.5547$, $N_p = 1.5527$, $N_g - N_p = 0.0183$. Weakly pleochroic with X = brick red, Y = scarlet, Z = blood red.

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[47] K. Kasporava: *Tables Ann. Intern. Const.*, V, 1925.

[48] F. Zambonini: *Atti. Accad. Lincei Rom.* (6), III, 1926, p. 644.

$K_3Fe(CN)_6$ is monoclinic with $a : b : c = 1.288 : 1 : 0.801$, $\beta = 89° 54'$. Crystals prismatic with 110, 100, 322, $12\bar{2}$, 111 (see Fig. 196) often twinned on 100; perfect 100 cleavage. G. = 1.85. The optic plane is 010; $Z \wedge c = + 3° 53'$. (+) 2E = 71° 20′ Li, 75° 52′ Na, increasing with temperature. 2V = 49°. $N_g = 1.5759$ B, 1.5831 D, $N_m = 1.5615$ B, 1.5689 D, $N_p = 1.5591$ B, 1.5660 D, $N_g - N_p = 0.0171$ D. Pleochroic with X = orange to clear red, Y = hyacinth to cherry red, Z = cherry red; X < Z < Y.

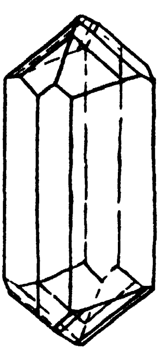

Fig. 196.—A crystal habit of potassium ferricyanide. (After Groth).

$K_3Rh(CN)_6$ is monoclinic with $a : b : c = 1.286 : 1 : 0.811$, $\beta = 89° 31'$. Crystals prismatic often twinned on 100; also pyramidal. The optic plane is 010; $Z \wedge c = 0°$. (+) 2E = 62° 55′ Li, 63° 35′ Na, 64° 23′ Tl. 2V = 39°. $N_g = 1.5634$ Na, $N_m = 1.5513$, $N_p = 1.5498$, $N_g - N_p = 0.0126$. Colorless.

10. HYDROUS HALIDES AND CYANIDES OF TRIVALENT AND MONOVALENT BASES

$NaAuCl_4 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.700 : 1 : 0.546$. Crystals six-sided prisms[50] (110, 010, 111 and 021). (+) 2V = ? $N_g = 1.75 +$, $N_m = ?$, $N_p = 1.545$, $N_g - N_p = 0.205 +$. Serves as a microchemical test for gold.

11. HALIDES AND CYANIDES OF TRIVALENT AND DIVALENT BASES

$Y_2Pt_3(CN)_{12} \cdot 21H_2O$ is orthorhombic with $a : b : c = 0.892 : 1 : 0.616$. Crystals 001 plates (001, 110, 111, 221) with perfect 001 cleavage. Twinning on 110, the optic plane[51] is 010; Z = c. (+) 2E = 28° Li, 23° Na; 2V = 15° ± Na. $N_g = 2.058$ He red, 2.055 C, $N_m = ?$, $N'_p = 1.5899$ He red, 1.5907 C, $N_g - N_p = 0.46$. Color deep red; pleochroic in violet and orange tints.

$Ce_2Pt_3(CN)_{12} \cdot 18H_2O$ is monoclinic with $a : b : c = 0.581 : 1 : 0.553$, $\beta = 72° 27'$. Crystals prismatic without distinct cleavage. Twinning on 100. G. = 2.66. (+) 2V[52] = ?, $N_g = 1.68$, $N_m = 1.66$,

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[50] Optic data by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275), on "sodium gold chloride" of unknown formula.

[51] *Zeit. Kryst.*, XLIX, 1911, p. 122.

[52] Optic data by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) "cerium platinum cyanide" of unknown formula.

N_p = 1.65, $N_g - N_p$ = 0.03. Color pale yellow with bluish fluorescence.

12. ANHYDROUS HALIDES AND CYANIDES OF TETRAVALENT AND MONOVALENT BASES

K_2SiF_6 is isometric with perfect 111 cleavage. Crystals cubic or octahedral. G. = 2.75. Isotropic[53] with N = 1.3391. If alumina is present the index may be about 1.39. Colorless. Made by slow cooling of a hot H_2O solution; serves as a micro-chemical test for potassium; the natural substance, called *hieratite*, is found as a rarity about volcanoes. By complete evaporation of a solution at about 10° C. hexagonal crystals may form in thin basal tablets which have c = 1.60, G. = 3.08, perfect basal cleavage, uniaxial negative character and weak birefringence.

$(NH_4)_2SiF_6$ is isometric with perfect 111 cleavage. Crystals octahedral. G. = 2. Isotropic with N = 1.3682 C, 1.3696 D, 1.3723 F. Colorless. Made from H_2O solution above 13° C. The natural substance, called *cryptohalite*, is found rarely about volcanoes and as a sublimate near a burning coal seam. By evaporating a solution at about 5° C. hexagonal crystals form as basal tablets which have c = 1.655, G. = 2.15, perfect basal cleavage and negative uniaxial character with N_o = 1.406 Na, N_e = 1.391, $N_o - N_e$ = 0.015 (nat. cryst.).

$(NH_4)_3ZrF_7$ is isometric[54] and octahedral with N = 1.433 D. Formed from solutions with excess of NH_4F.

K_2PtCl_6 is isometric; crystals octahedral or cubic with good 111 cleavage. G. = 3.6–3.7. Isotropic with N = 1.827 (577 mμ).[53] Color yellow.

$(NH_4)_2PtCl_6$ is isometric and octahedral with perfect 111 cleavage. G. = 3.0. Isotropic[55] with N = 1.8.

K_2SnCl_6 is isometric; crystals octahedral with perfect 111 cleavage. G. = 2.69. Isotropic with N = 1.6517 C, 1.6574 D, 1.6717 F. Colorless.

$(NH_4)_3HfF_7$ is isometric[56] with N = 1.426 D.

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[53] *Atti Accad. Lincei, Rom.*, XXI, 1922, p. 112. Also *Zeit. anorg. Chem.*, LXXXVII, 1914, p. 55.

[54] *Int. Crit. Tables*, I, 1926, p. 114.

[55] F. J. Moore and E. S. Gatewood: *Jour. Am. Chem. Soc.*, XLV, 1923, p. 145 and E. S. Gatewood, *ibid.*, p. 3059.

[56] *Int. Crit. Tables*, I, 1926, p. 140.

K_3ZrF_7 is isometric[57] and octahedral with N = 1.408. Formed from solutions with excess of KF.

K_2TiF_6 is trigonal[57a] with C = 0.814; crystals often tabular on $10\bar{1}1$; twinning common on $10\bar{1}1$. G. = 3.01. Uniaxial negative with $N_o = 1.475$, $N_e = ?$, $N_o - N_e$ = weak. Easily formed from solution.

Na_2SiF_6 is pseudohexagonal (orthorhombic) with $c = 0.564$. Crystals prismatic. Twinning on 110 as in aragonite. G. = 2.75. X = *c*. Biaxial negative of small optic angle. N_g (nearly $= N_m$) = 1.3117 (649), 1.3125 Na, 1.3138 (501), $N_p = 1.3089$, $N_g - N_p$ = 0.0036 (Raiteri).[53] The natural substance has been named *malladrite.*[58] Crystals serve as a microchemical test for sodium.

K_2ZrF_6 is monoclinic[59] with $a : b : c = 0.573 : 1 : 0.597$, $\beta = 89°\ 40'$; crystals prismatic with 001 cleavage and G. = 3.58. Lamellar twinning on 100 and 001. Soluble in hot water. The optic plane is normal to 010; $Z \wedge c = 45°$. (+) 2V = 60°, $N_g = (1.498)$, N_m = 1.465, $N_p = 1.454$, $N_g - N_p = (0.044)$. Colorless.

13. HYDROUS HALIDES AND CYANIDES OF TETRAVALENT AND DIVALENT BASES

$MgSiF_6 \cdot 6H_2O$[60] is trigonal with $c = 0.517$; crystals prismatic to rhombohedral with perfect $11\bar{2}0$ cleavages. G. = 1.76. Uniaxial positive with $N_o = 1.3427$ C, 1.3439 D, 1.3473 F, $N_e = 1.3587$ C, 1.3602 D, 1.3634 F, $N_e - N_o = 0.0163$ D. Colorless. Crystals serve as a microchemical test for magnesium.

$MnSiF_6 \cdot 6H_2O$[60] is trigonal with $c = 0.504$; crystals prismatic with perfect $11\bar{2}0$ cleavages. G. = 1.86. Uniaxial positive with $N_o = 1.3552$ C, 1.3570 D, 1.3605 F, $N_e = 1.3721$ C, 1.3742 D, 1.3774 F, $N_e - N_o = 0.0172$ D. Color pink. Made by reaction of HF on manganese silicates.

$FeSiF_6 \cdot 6H_2O$[60] is trigonal with $c = 0.503$; crystals like those of $MgSiF_6 \cdot 6H_2O$. Uniaxial positive with $N_o = 1.3619$ Li, 1.3638 Na,

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[57] *Int. Crit. Tables,* I, 1926, p. 156

[57a] F. Zambonini: *Bull. Soc. Fr. Min.,* LIII, 1931, p. 463.

[58] *Atti. Accad. Lincei Rom,* (6), IV, 1926, p. 171.

[59] *Univ. Toronto Studies, Geol. Ser.,* XX, 1925, p. 63.

[60] The studies of Boehm (*Zeit. anorg. Chem.,* XLIII, 1905, p. 330), and of Edmister and Cooper (*Jour. Am. Chem. Soc.,* XLII, 1920, p. 2419), make it very probable that the supposed silicofluorides of cobalt, nickel, manganese and copper are actually acid fluorides, containing no silicon, of the type $RF_2 \cdot 5HF \cdot 6H_2O$. By inference the other silicofluorides of divalent bases are called in question. It may be added that the indices given seem lower than normal for such silicofluorides.

1.3656 Tl, N_e = 1.3828 Li, 1.3848 Na, 1.3867 Tl, $N_e - N_o$ = 0.0210 Na. Colorless. Made by reaction of HF on iron silicates. Crystals serve as a microchemical test for iron.

NiSiF$_6\cdot$6H$_2$O[60] is trigonal with c = 0.514; crystals long prismatic with perfect $11\bar{2}0$ cleavages. G. = 2.13. Uniaxial positive with N_o = 1.3876 C, 1.3910 D, 1.3950 F, N_e = 1.4036 C, 1.4066 D, 1.4105 F, $N_e - N_o$ = 0.0156 D. Color apple green. Made by reaction of HF on nickel silicates.

CoSiF$_6\cdot$6H$_2$O[60] is trigonal with c = 0.522; crystals prismatic to rhombohedral with distinct $11\bar{2}0$ cleavages. G. = 2.09. Uniaxial positive with N_o = 1.3817 C, N_e = 1.3872, $N_e - N_o$ = 0.0055. Color red.

CuSiF$_6\cdot$6H$_2$O[60] is trigonal with c = 0.540; crystals thick prismatic, unstable, with indistinct $11\bar{2}0$ cleavages. G. = 2.21. Uniaxial negative with N_o = 1.4074 C, 1.4092 D, 1.4138 F, N_e = 1.4062 C, 1.4080 D, 1.4124 F, $N_o - N_e$ = 0.0012 D. Color blue.

ZnSiF$_6\cdot$6H$_2$O[60] is trigonal with c = 0.517; crystals prismatic with perfect $11\bar{2}0$ cleavages. G. = 2.14. Uniaxial positive with with N_o = 1.3808 C, 1.3824 D, 1.3860 F, N_e = 1.3938 C, 1.3956 D, 1.3992 F, $N_e - N_o$ = 0.0132 D. Colorless.

MgSnCl$_6\cdot$6H$_2$O is trigonal with c = 0.508; crystals rhombohedral with perfect $11\bar{2}0$ cleavages. G. = 2.08. Uniaxial positive with N_o = 1.5715 C, 1.5885 D, N_e = 1.583 C, 1.597 D, $N_e - N_o$ = 0.0085 D. Colorless.

14. HALIDES OF HEXAVALENT AND MONOVALENT BASES

(NH$_4$)$_3$UO$_2$F$_5$ is tetragonal with c = 0.9 +. Crystals pyramidal; often with cruciform twinning. G. = 4.26. Uniaxial negative[61] with N_o = 1.495, N_e = 1.49, $N_o - N_e$ – 0.005.

Cs$_2$UO$_2$Cl$_4$ is triclinic[62] with 010 $\wedge$ 110 = 49° 7′ and 010 $\wedge$ 011 = 40° 31′; crystals resembling those of gypsum, much twinned. $Z' \wedge c$ in 010 = 15°. A prism parallel to c gives N_1 = 1.695, N_2 = 1.625 and a prism parallel to a gives N_3 = 1.614, N_4 = 1.691. Color yellow.

(NH$_4$)$_2$UO$_2$Cl$_4\cdot$2H$_2$O is triclinic[62] with $a : b : c$ = 0.61 : 1 : 0.56. α = 81°, β = 78°, γ = 91°. Crystals 001 or 010 tablets. N'_g =

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[61] Optic data by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) on "ammonium uranium fluoride"—Formula unknown.

[62] E. L. Nichols and H. L. Howes: *Carn. Inst. Publ.*, 298, 1919, p. 217.

1.637, $N'_m = 1.633$, $N'_p = 1.566 - 1.574$ ∴ (–) 2V = small. $N'_g - N'_p = 0.063 - 0.071$. Color yellow with X = colorless, Y = deep yellow.

15. HALIDES WITH AMMONIA

$PtCl_2 \cdot 4NH_3 \cdot nH_2O$ is tetragonal[63] with $c = 1.11 \pm$. Crystals short plates. Uniaxial and negative with $N_o = 1.612$, $N_e = 1.607$, $N_o - N_e = 0.005$. Color brownish yellow. Formed by evaporating an aqueous solution.

$PtCl_2 \cdot 2NH_3 \cdot 4(PtCl_2 \cdot 4NH_3)$ is tetragonal[63] with $c = 1.111$. Crystals isomorphous with Pd compound. Uniaxial and negative with $N_o = 1.666$, $N_e = 1.658$, $N_o - N_e = 0.008$. Color brownish yellow.

$ZnCl_2 \cdot 6NH_3$ is hexagonal[64] prismatic with perfect 0001 cleavage. H. = 1. Soluble in water. Uniaxial negative with $N_o = 1.539$, $N_e = ?$, $N_o - N_e = 0.009 \pm$. Colorless. Formed in an electric battery.

$IrCl_3 \cdot 4NH_3 \cdot H_2O$ is trigonal with $c = 0.645$. Crystals prismatic. Uniaxial positive with $N_o = 1.6576$, $N_e = 1.6666$, $N_e - N_o = 0.009$.

$KPtCl_3 \cdot NH_3 \cdot H_2O$ is orthorhombic with $a : b : c = 1.262 : 1 : 0.823$. Crystals prismatic with 101; no distinct cleavage. The optic plane is 100; X = c. (–) 2V = 64° ±. $N_g = 1.588 \pm$, $N_m = 1.5754$, $N_p = 1.5438$, $N_g - N_p = 0.044 \pm$. Color reddish yellow and pleochroic with X = yellowish red, Y = reddish yellow, Z = deep yellow or red.

$ZnCl_2 \cdot 2NH_3$ is orthorhombic[64] with $a : b : c = 0.916 : 1 : 0.951$. Crystals 110 twinned plates or pseudotetragonal forms like pyramids on the b axis. Twinning on 011 (with 110 as the composition face) in crosses. Perfect 011 and 010 cleavages. H. = 1. G. = 1.95. Soluble in water. The optic plane is 010; Z = c. (+) 2V = large (86° in glycerine). $N_g = ?$, $N_m = 1.618 \pm$, $N_p = ?$, $N_g - N_p = ?$. Colorless. Formed in an electric battery.

16. OXYHALIDES

Hg_3OCl_4 is isometric[65] in dodecahedrons or octahedrons with G. = 6.39 and N = 2.001 Na.

$ZrOCl_2 \cdot 8H_2O$ is tetragonal with $c = 0.318$. Crystals prismatic with 100 cleavage. Soluble in HCl. Uniaxial[66] positive with $N_o = 1.552$, $N_e = 1.563$, $N_e - N_o = 0.011$.

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[63] *Zeit. anorg. Chem.*, CLXXIX, 1930, p. 137.

[64] K. Chuboda: *Cent. Min.*, 1929, A, p. 139.

[65] E. Carozzi: *Gazz. Chim. Ital.*, LVI, 1926, p. 175. *Tables Am. Const. Phys.*, VII, 2, 1930, p. 1488.

$HfOCl_2 \cdot 8H_2O$ is uniaxial[66] negative with $N_o = 1.557$, $N_e = 1.543$, $N_o - N_e = 0.014$.

$3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10H_2O$ is hexagonal[67] in thin basal plates with $c = 2.067$. Uniaxial negative with $N_o = 1.550$, $N_e = 1.535$, $N_o - N_e = 0.015$. Colorless. Below 36° C. it is monoclinic and pseudohexagonal in basal plates with complex twinning and $a : b : c = 0.579 : 1 : 1.378$, $\beta = 87° \ 20'$, G. = 1.89. The optic plane is 010; an optic axis is nearly normal to 001.

$Ca_2OCl_2 \cdot 2H_2O$ is hexagonal[68] and prismatic; uniaxial and negative with $N_o = 1.638 \pm$, $N_e = 1.634 \pm$, $N_o - N_e = 0.004 \pm$. Colorless.

$Ca_5O_4Cl_2 \cdot 14H_2O$ (?) is orthorhombic[68] with perfect 001 cleavage. The optic plane is 100; $X = a$. (−) $2V = 45°$, $N_g = 1.537$, $N_m = 1.533$, $N_p = 1.517$, $N_g - N_p = 0.020$. Colorless. Similar crystals[68] probably containing CO_2 have $N_g = 1.558$, $N_m = 1.544$, $N_p = 1.478$, $N_g - N_p = 0.080$.

IV CYANATES AND THIOCYANATES

1. CYANATES

NaCNO is hexagonal[1] with rhombohedral cleavage. Uniaxial positive with $N_o = 1.389$, $N_e = 1.627$, $N_e - N_o = 0.238$.

2. THIOCYANATES OF MONOVALENT BASES

NaCNS forms[2] clear prismatic crystals, probably orthorhombic, with negative elongation and parallel extinction. (−) $2V = 82° \pm 3°$ (calc.). $N_g = 1.695 \pm .005$, $N_m = 1.625 \pm .003$, $N_p = 1.545 \pm .005$, $N_g - N_p = 0.150 \pm .01$. Colorless.

KCNS forms[2] long prismatic crystals, probably monoclinic, with positive elongation and $Z \wedge c = 16° \pm$. (−) $2V = 68° \pm 3°$ (calc.). $N_g = 1.730 \pm .005$, $N_m = 1.660 \pm .005$, $N_p = 1.532 \pm .003$, $N_g - N_p = 0.198 \pm .01$. Colorless.

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[66] *Int. Crit. Tables*, I, 1926, p. 140.

[67] L. S. Wells: *Bur. Stand. Jour. Res.*, I, 1928, p. 951.

[68] Properties measured by H. E. Merwin—personal communication, Mar. 25, 1931. Formula of the orthorhombic salt from *Chem. Weekb.*, VIII, 1911, p. 683; other formulas given in *U. S. Bur. Stand. Tech. Pap.*, 174, 1920.

[1] Properties determined by H. E. Merwin—personal communication, Mar. 25, 1931.

[2] V. A. Vigfusson—personal communication, Sept. 30 and Nov. 29, 1930.

NH_4CNS is monoclinic[3] with $a : b : c = 2.035 : 1 : 2.367$, $\beta = 62°$ $58'$; crystals 100 plates or prisms with perfect 100 and $10\bar{1}$ cleavages. The optic plane is 010 and $Z \wedge c = 22°$ (Vigfusson[2]); $X \wedge \perp 10\bar{1} = 18°$ (Gossner)[3]. $(-)\ 2V = 23° \pm 3°$ (calc.), $\rho < v$ strong and also inclined dispersion. $N_g = 1.692 \pm .003$, $N_m = 1.685 \pm .003$, $N_p = 1.546 \pm .003$, $N_g - N_p = 0.146 \pm .006$ (Vigfusson[2]). Colorless.

3. THIOCYANATES OF DIVALENT AND MONOVALENT BASES

$Cs_3Ag_2Ba(CNS)_7$ is tetragonal with $c = 0.906$. Crystals short prismatic with 201. Perfect 001 cleavage. G. = 3.03. Uniaxial negative with $N_o = 1.7761$, Na, $N_e = 1.6788$, $N_o - N_e = 0.0973$.

$Cs_3Cu_2Ba(CNS)_7$ is tetragonal with $c = 0.918$. Crystals short prismatic with 201 or 001. Perfect 001 cleavage. G. = 2.92. Uniaxial negative with $N_o = 1.8013$ Na, $N_e = 1.6882$, $N_o - N_e = 0.1131$.

$Cs_3Cu_2Sr(CNS)_7$ is tetragonal with $c = 0.916$. Crystals short prismatic with 201 and 001. Perfect 001 cleavage. G. = 2.88. Uniaxial negative with $N_o = 1.8535$, $N_e = 1.6982$, $N_o - N_e = 0.1553$.

$KHg(CNS)_3$ is orthorhombic[4] in acicular crystals with $011 \wedge 0\bar{1}1 = 158° \pm$. The optic plane is 100; $X = c$. $(-)\ 2V = 65° - 70°$, $\rho < v$ strong. N_g[5] $= 1.880 \pm$, $N_m = 1.843$, $N_p = 1.730$, $N_g - N_p = 0.150$.

$K_2Hg(CNS)_4$ is monoclinic;[4] crystals varied in habit with $110 \wedge 1\bar{1}0 = 80° \pm$, $\beta = 74° \pm$, $X \wedge a = 22°$, Y nearly $= c$, $Z = b$. $(-)\ 2V =$ nearly 90°, $\rho > v$ strong. $N_g = 1.9+$ (est.), $N_m = 1.80$ (est.), $N_p = 1.645$, $N_g - N_p = 0.255$ (est.).

V. OXIDES

The oxides are here arranged, first in the order of increasing valence of the element combined with oxygen and second in the order of decreasing symmetry,—the anhydrous oxides being considered before the hydrous.

1. OXIDES OF MONOVALENT ELEMENTS

Li_2O is isometric with the CaF_2 space lattice; distinct cleavage. G. = 2.01. F. = above 1625° C., but sublimes below 1000°, and oxidizes to Li_2O_2 at lower temperatures. Soluble in water. Isotropic[1] with N = 1.644; also anisotropic (from strain?). Colorless or stained yellow by Li_2O_2.

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[3] Groth. *Chem. Kryst.*, II, 1908, p. 3.

[4] C. W. Mason and W. D. Forgeng: *Jour. Phys. Chem.*, XXXV, 1931, p. 1123.

[5] Indices measured by H. E. Merwin—personal communication, Mar. 25, 1931.

Cu_2O is isometric in octahedrons, cubes, or combinations, with poor 111 cleavage. The space lattice is shown in Fig. 190. H = 3.5-4. G. = 5.975. Isotropic with N = 2.534 B, 2.558 C, 2.705 D, 2.963 F. Color bright red. Made by electrolytic deposition, etc. The natural substance, called *cuprite*, is found in the oxide zone of copper deposits; it may alter to copper or to malachite, etc.

H_2O is hexagonal with c = 1.62. Complete crystals rare; skeleton (*snow*) crystals very common as hexagonal basal tablets. Basal gliding plane developed by pressure. H. = 1.5. G. = 0.918. Melts to *water* at 0° C. (which has N = 1.333). Uniaxial positive with[2] N_o = 1.3071 C, 1.3090 D, 1.3133 F, N_e = 1.3086 C, 1.3104 D, 1.3147 F, $N_e - N_o$ 0.0014 D (data for −3° C.). Colorless (to pale blue in mass). The natural substance, *ice*, is common as a temporary constituent of surface rocks during cold weather; also abundant as a coating over lakes, and as masses (over land) called glaciers, whose texture is like that of granular limestone. In the form of frost, often dendritic, stellate, etc.

2. ANHYDROUS OXIDES OF DIVALENT ELEMENTS

MgO is isometric[3] in cubes, octahedrons and grains with perfect 100 and imperfect 111 cleavages. Crystals have the NaCl space lattice. H. = 5-5.5. G. = 3.58. F. = 2800° ± C. Isotropic with N = 1.734-1.737. Pure MgO has[4] N = 1.7335 C, 1.7366 D, 1.7475 F. Colorless. Made from fusion, etc. The natural substance called *periclase*, is found as a rarity chiefly in contact zones.

CaO is isometric with the NaCl space lattice. Crystals cubic with perfect cubic cleavage.[5] H. = 3-4. G. = 3.32. Fuses at 2570° C.

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[1] F. M. Jaeger: *Proc. K. Akad. Wet. Amst.*, XVI, 1914, p. 857.

[2] *N. J. Min. Bl. Bd.* XLI, 1917, p. 362.

[3] Shepherd, Rankin and Wright: *Am. Jour. Sci.*, CLXXVIII, 1909, p. 293. N. L. Bowen and O. Andersen: *Am. Jour. Sci.*, CLXXXVII, 1914, p. 487. G. A. Rankin and H. E. Merwin: *Jour. Am. Chem. Soc.*, XXXVIII, 1916, p. 568. J. B. Ferguson and H. E. Merwin: *Am. Jour. Sci.*, CXCVIII, 1919, p. 81.

[4] M. Haase: *Zeit. Kryst.*, LXV, 1927, p. 509.

[5] G. A. Rankin and F. E. Wright: *Am. Jour. Sci.*, CLXXII, 1906, p. 294, CLXXXIX, 1915, p. 1. Sosman, Hostetter and Merwin: *Jour. Wash. Acad. Sci.*, V, 1915, p. 566. J. B. Ferguson and H. E. Merwin: *Am. Jour. Sci.*, CXCVIII, 1919, p. 81. White's test for free lime {CaO or $Ca(OH)_2$} may be made by adding a solution of phenol in nitrobenzene to form calcium phenolate {$Ca(C_6H_2O)_2$} which forms tetragonal acicular prisms,

Soluble in acid. Hydrates rapidly in moist air. Isotropic with N = 1.833 C, 1.837 D, 1.846 (530). Reversible inversion at about 420° C., both forms being isotropic. As made from fusion it is in round grains. Colorless.

SrO is isometric with the NaCl space lattice. Crystals cubic with perfect cubic cleavage. G. = 4.75; [6] 5.14.[7] Isotropic with N = 1.856 C, 1.870 D, 1.880 (535). Colorless. Reacts with moisture even at high temperature. Miscible in all proportions with CaO. Made from fusion.

CdO is isometric and octahedral or cubic with (111 ?) cleavage. G. = 8.15 ±. Isotropic [7a] with N = 2.49 ± Li. Color brown or red to black.

BaO is isometric with the NaCl space lattice. Crystals cubic with perfect cubic cleavage. G. = 5.72;[4] 6.09.[7] Isotropic with N = 1.958 C, 1.980 Na,[6] 2.002 (520); 2.16 Li.[7] Colorless. Reacts with moisture even at high temperature. Made from fusion.

NiO is isometric with the NaCl space lattice. Crystals octahedral with H. = 5.5. G. = 6.80. F. = 7. Soluble in acid. Isotropic [7b] with N = 2.37 Li. Color deep green (or brownish black). Made by oxidation of nickel. The natural substance, called *bunsenite*, is very rare.

PbO is tetragonal (= *lithargite*) and orthorhombic (= *massicotite*). The tetragonal crystals are basal tablets with perfect prismatic cleavage. H. = 2. G. = 9.13. F. = 1.5. Soluble in HNO_3. Uniaxial negative with $N_o = 2.665$ Li, $N_e = 2.535$ Li, $N_o - N_e = 0.13$. Color yellowish red. Artificial "litharge" is a mixture with lithargite crystals bordering massicotite, from which they are doubtless derived. Rare natural crystals show a similar condition.

The orthorhombic PbO crystals are 100 tablets with $a : b : c = 0.671 : 1 : 0.976$; perfect 100 cleavage. Soft. G. = 9.29. F. = 1.5. Soluble in HNO_3. Axis Y (or X?) normal to 100. Optic angle very large, positive (negative in blue) with strong dispersion. $N_g = 2.71$ Li, $N_m = 2.61$, $N_p = 2.51$, $N_g - N_p = 0.20$. Color yellow; streak lighter; pleochroic with X (or Y?) light sulphur yellow, Z deep yellow.

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often in clusters; uniaxial negative with $N_o = 1.650 \pm 0.003$ N_a, $N_e = 1.528 \pm 0.003$, $N_o - N_e = 0.122 \pm 0.005$ as measured by V. A. Vigfusson at the University of Wisconsin.

[6] K. Spangenberg: *Naturwiss.*, XV, 1927, p. 266.

[7] P. Eskola: *Am. Jour. Sci.*, CCIV, 1922, p. 331.

[7a] Index measured by H. E. Merwin—personal communication, Mar. 25, 1931.

[7b] Index and density measured by H. E. Merwin—personal communication, Mar. 25, 1931.

BeO is hexagonal with $c = 1.63$; crystals prismatic with distinct $10\bar{1}0$ cleavage. H. = 9. G. = 3. Insoluble in acid. Uniaxial positive with $N_o = 1.719$, $N_e = 1.733$, $N_e - N_o = 0.014$. Color white. Recently found in nature and named *bromellite*.[8]

ZnO is hexagonal, hemimorphic, with $c = 1.622$ and perfect basal cleavage. Crystals often prismatic. H. = 4–4.5. G = 5.43–5.7. F. = 7. Soluble in HCl. Uniaxial positive[9] with $N_o = 1.984$ C, 2.004 D, 2.065 F, $N_e = 2.000$ C, 2.020 D, 2.081 F, $N_e - N_o = 0.016$ D. Color red, not pleochroic. Alters to zinc carbonate. The natural substance is called *zincite*.

CuO is monoclinic[10] with $a : b : c = 1.490 : 1 : 1.360$, $\beta = 80° \, 28'$. Crystals lath-shaped, twinned, with 111 and 001 cleavages. H. = 3–4. G. = 6.45. F. = 3. Soluble in HCl. The acute bisectrix (X) is nearly normal to plates in which Z is parallel with the elongation. Dispersion $\rho < v$. N = 2.63 (red), 2.84 (white), 3.18 (blue), $N_g - N_p$ = strong. Color and streak black to iron gray. Absorption very strong with Y < Z and Y = light brown, Z = nearly opaque brown. Made by oxidation of copper. The natural substance, called *tenorite* or *melaconite*, is rare in the oxide zone of copper deposits.

3. HYDROUS OXIDES OF DIVALENT ELEMENTS

$Sr(OH)_2 \cdot 8H_2O$ is tetragonal with $c = 0.64$; crystals basal plates with 001 and 110 cleavages; twinning common on 110, 101, or 210. G. = 1.885. Uniaxial negative with $N_o = 1.499$, $N_e = 1.476$, $N_o - N_e = 0.023$. Colorless. Made from solution.

$Ca(OH)_2$ is hexagonal with $c = 1.40$; perfect basal cleavage. H. = 2.5. G. = 2.23. Uniaxial negative[11] with $N_o = 1.574$, $N_e = 1.545$, $N_o - N_e = 0.029$. Colorless. Reacts with clove oil. Formed by hydration of lime out of contact with CO_2 (or the air).

$Ba(OH)_2 \cdot 8H_2O$ is monoclinic with $a : b : c = 0.999 : 1 : 1.278$, $\beta = 81° \, 4'$; crystals complex, more or less flattened parallel to 001 or elongated parallel to *a*. Perfect basal cleavage. G. = 2.08. The optic plane is normal to 010; X nearly normal to 001: $(-)\ 2E = 20°$, $2V = 8° \, 33'$ Na, $N_g = 1.502$, $N_m = 1.5017$, $N_p = 1.471$, $N_g - N_p = 0.031$. Colorless. Made from H_2O solution.

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[8] G. Aminoff: *Zeit. Kryst.*, LXII, 1925, p. 113.

[9] H. E. Merwin: *Proc. Am. Soc. Test. Mat.*, XVII, 1917, Pt. 2.

[10] E. Posnjak and G. Tunell: *Am. Jour. Sci.*, XVIII, 1929, p. 1.

[11] F. W. Ashton and R. Wilson: *Am. Jour. Sci.*, CCXIII, 1927, p. 209.

4. ANHYDROUS OXIDES OF TRIVALENT ELEMENTS

B_2O_3 glass [1] is isotropic with N = 1.4637 Na;[12] 1.459 ± 0.002 D.[13] Colorless. Made from fusion.

As_2O_3 has two crystal phases.[14] One is isometric and octahedral or fibrous, with octahedral cleavage. H. = 1.5. G. = 3.71. F. = 1, volatile. Isotropic with N = 1.748 Li, 1.755 Na. Colorless. Made by sublimation. The natural substance, called *arsenolite*, is an oxidation product of arsenic ores.

The other phase of As_2O_3 is monoclinic with $a : b : c = 0.404 : 1 : 0.345$, $\beta = 86° 3'$. Crystals prismatic or 010 tablets with perfect 010 cleavage. Twinning common on 100 or penetration type. H. = 2.5. G. = 3.85. F. = 1, volatile. The optic plane is 010; $Z \wedge c = +6°$; (+) $2V = 58°$, $\rho < v$ strong. $N_g = 2.01$, $N_m = 1.92$, $N_p = 1.87$, $N_g - N_p = 0.14$. Colorless. Made from solution. The natural substance, called *claudétite*, is an oxidation product of arsenic ores.

Al_2O_3 has three crystal phases.[15] The most stable phase is trigonal with $c = 1.363$. Crystals 0001 tablets limited by the rhombohedron (see Fig. 197). No cleavage, but may have basal parting. H. = 9. G. = 4. F. = 2050° C. Insoluble in acids. Uniaxial negative with $N_o = 1.768$, $N_e = 1.760$, $N_o - N_e = 0.008$. Also $N_o = 1.7681 - 1.7714$ C, 1.7715–1.7745 D, 1.7789–1.7818 F, $N_e = 1.7630$–1.7667 (Melczer [16]); $N_o = 1.7704$–1.7813, $N_e = 1.7619 - 1.7726$ (on artificial ruby). Colorless or tinted blue, red, etc., by impurities. Made from fusion. The natural substance, called *corundum*, is found in contacts, slates, etc.

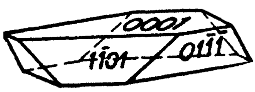

FIG. 197.—A basal plate of Al_2O_3.

The second phase of Al_2O_3 is hexagonal in triangular plates with perfect basal cleavage. G. = 3.31. Stability relations unknown, but apparently monotropic. Uniaxial negative with $N_o = 1.665$–1.680, $N_e = 1.63$–1.65, $N_o - N_e = 0.025$–0.045. Colorless.

The third phase of Al_2O_3 is isometric [17] with G. = 3.47 and [18] N =

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[12] Bedson and Williams: *Ber. chem. Ges.*, XIV, 1881, p. 2553.

[13] H. E. Merwin—personal communication, Mar. 8, 1930.

[14] A. Des Cloizeaux: *Comp. Rend.*, CV, 1887, p. 96. Indices of claudétite from Larsen (*U. S. G. S. Bull.* 679, 1921, p. 58), on natural crystals.

[15] Shepherd, Rankin and Wright: *Am. Jour. Sci.*, CLXXVIII, 1909, p. 293. G. A. Rankin and H. E. Merwin: *Am. Jour. Sci.*, CXCV, 1918, p. 301.

[16] *Zeit. Kryst.*, XXXV, 1902, p. 561; see also R. Brauns: *Cent. Min.*, 1926, A, p. 233.

[17] F. Ulrich: *Min. Abst.*, III, 1926, p. 21.

[18] Hansen and Brownmiller: *Am. Jour. Sci.*, CCXV, 1928, p. 229.

1.696. It may be prepared by heating precipitated alumina to 925° C. for some hours. Ignited alumina hydrogel has N = 1.68 (1.65–1.69). It is amorphous. It changes to corundum on heating for an hour at 1000° to 1200° C.

Fe_2O_3 has two or three crystal phases. The common phase is trigonal with $c = 1.359$. Crystals rhombohedral or basal plates. See Fig. 198. May have basal parting. H. = 5. G. = 5.2. F. = 7. Soluble in HCl. Uniaxial negative[19] with $N_o > 2.95$ Li, $N_e = 2.74$, $N_o - N_e = 0.21+$. Also[20] $N_o = 3.01$ Li, $N_e = 2.78$, $N_o - N_e = 0.23$. By partial deoxidation (17.8 per cent FeO) $N_e = 2.71$ and (with 16.1 FeO) $N_o - N_e = 0.16+$. Deoxidation may be carried to 31.8 per cent FeO. Color of crystals steel gray to iron black; color in mass, deep red in reflected light; opaque except in thin scales which are blood red with X = yellowish red, Z = brownish red. Made in a steel bomb. The natural substance, called *hematite*, is common and widely disseminated. *Hydrohematite* or *turgite* is a fibrous variety of hematite[21] with adsorbed water. G. = 4.5–5. Uniaxial negative with $N_o = 2.5–2.7$, $N_e = 2.3–2.6$, $N_o - N_e = 0.1$ to 0.2. Parallel extinction and negative elongation. Color lighter red than hematite.

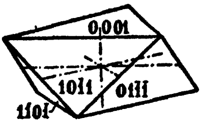

FIG. 198.—A basal plate of Fe_2O_3.

Fe_2O_3 inverts promptly at 678° C. and is said to invert also at −40° C., but optic data on these forms are lacking. Fe_2O_3 is miscible[22] with Cr_2O_3 in all proportions, and with Al_2O_3 to a limited extent. Al_2O_3 is miscible in Fe_2O_3 up to about 12 per cent, but very little Fe_2O_3 can enter the Al_2O_3 space lattice.

Cr_2O_3 is trigonal with $c = 1.377$ and G. = 5.2. Crystals equant prismatic to basal tablets. Twinning common especially on 0001. Distinct rhombohedral cleavage. Uniaxial positive[23] with N = 2.5 ±. Green in thin plates.

5. HYDROUS OXIDES OF TRIVALENT ELEMENTS

$Fe_2O_3 \cdot H_2O$ has two crystal phases; the common one is orthorhombic with $a : b : c = 0.91 : 1 : 0.607$. Crystals vertically striated prisms to fibers with perfect 010 and distinct 100 cleavages. H. = 5–5.5. G. = 4.3. F. = 5.5. Soluble in HCl. Dispersion of the optic axes is extreme so that the optic plane is 100 for red and 001 for yellow, green and blue in the common condition, and the mineral is uniaxial for light of wave-length 612 mμ. See Figs. 199, 200. The acute bisectrix, normal to 010, is negative for all colors. Elongation positive. Pure material[24] has: $N_g = 2.400$ Na, $N_m = 2.377$ (612), 2.394 Na, $N_p = 2.260$, $N_g - N_p = 0.140$. Often impure, especially with water adsorbed in fibrous masses and then: $N_m = 1.87$ (-2.40), $N_g - N_p = 0.06$ (-0.14). Color yellow with $a > c > b$. Made in a steel bomb. Impure aggregated material may be *apparently* isotropic with N = 2.00 ± to 2.15 ±. The natural pure substance, called *goethite*, is an oxidation product of iron minerals. The natural substance, *limonite*, seems to be goethite with adsorbed water.

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[19] R. B. Sosman and J. C. Hostetter: *Jour. Am. Chem. Soc.*, XXXVIII, 1916, p. 807.

[20] H. E. Merwin: *Proc. Amer. Soc. Test. Mat.*, XVII, 1917, pt. 2.

[21] E. Posnjak and H. E. Merwin: *Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1965.

[22] *Comp. Rend.*, CLXXX, 1925, p. 1264. *Am. Jour. Sci.*, CCXV, 1928, p. 230.

[23] P. Gaubert: *C. R. Cong. Soc. Sav. Sci.*, 1925. Also H. E. Merwin: *Proc. Am. Soc. Test. Mat.*, XVII, 1917, p. 2.

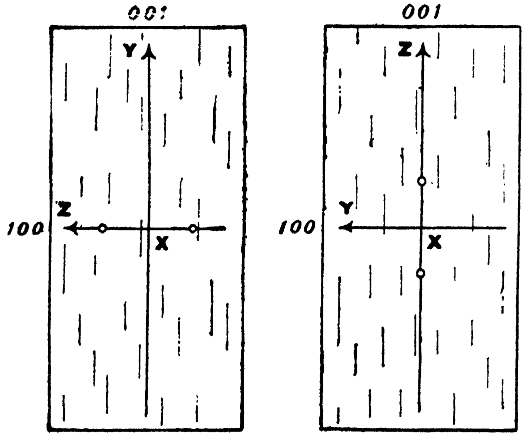

FIG. 199. FIG. 200.

FIGS. 199, 200.—Optic orientation of $Fe_2O_3 \cdot H_2O$ for blue and red, respectively.

The second phase of $Fe_2O_3 \cdot H_2O$ (*lepidocrocite*) has not been produced artificially.

$Al_2O_3 \cdot 3H_2O$, produced by precipitating alumina from solution,[18] is not the same as gibbsite, as shown by X-ray studies; it is faintly birefringent with N = 1.583, if dried at 110° C., and with N = 1.55 if dried with alcohol and ether. Called *bayerite* by Biltz.[25]

$Al_2O_3 \cdot H_2O$, prepared by heating $Al_2O_3 \cdot 3H_2O$ to about 200° C. for 50 hours, is amorphous[18] with N = 1.565. When prepared by hydrating Al_2O_3 in steam at 125 atmospheres it has[26] G. = 3.06, N = 1.65 and $N_g - N_p$ = weak—not like diaspore.

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[24] E. Posnjak and H. E. Merwin: *Am. Jour. Sci.*, CXCVII, 1919, p. 311, and *Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1965.

[25] W. Biltz: *Zeit. anorg. Chem.*, CLXXV, 1928, p. 249.

[26] Van Nieuwenburg and Peters: *Rec. Trav. Chim. Pays Bas*, XLVIII, 1929, p. 27.

6. OXIDES OF TETRAVALENT ELEMENTS

SnO_2 has three crystal phases; the most stable is tetragonal with $c = 0.672$. Crystals acicular to columnar prisms (see Fig. 201) or nearly equant pyramids with distinct prismatic cleavage. Twinning on 101; see Fig. 202. H. = 6–7. G. = 6.8–7.1. Uniaxial positive[27] with $N_o = 1.9846$ Li, 1.9968 Na, 2.0093 Tl, $N_e = 2.0817$ Li, 2.0929 Na, 2.1053 Tl, $N_e - N_o = 0.0961$ Na. Color brown, red, gray, yellow, colorless. Made in slags, etc. The natural substance, called *cassiterite*, is the important tin ore.

Hexagonal and orthorhombic phases of SnO_2 have been produced, but not measured optically.

PbO_2 is tetragonal with $c = 0.676$. Crystals ιatic with 110 cleavage. G. = 8.56. Uniaxial negative with N = 2.229 D. When made by fusion of lead oxide in potash the color is dark brown. The natural substance, called *plattnerite*, is found rarely in the oxide zone of lead deposits.

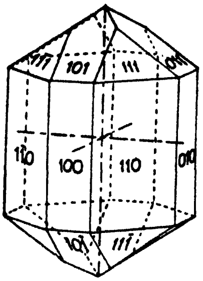

FIG. 201.—Unit and diametral tetragonal prisms and pyramids; cassiterite—SnO_2.

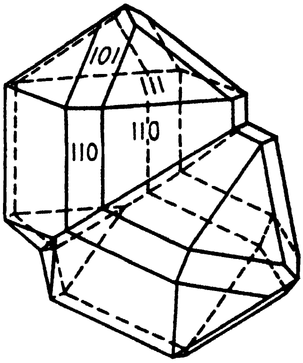

FIG. 202.—Geniculated twin in cassiterite, SnO_2.

SiO_2 has several crystal phases.[28] The high temperature phase is isometric in octahedral cubic or skeletal crystals with twinning on 111. H. = 6–7. G. = 2.27–2.35 (Longchambon[29]), F. = 1710° C. Insoluble in HCl. Isotropic above 200° to 275° C. with N = 1.486. Colorless. The high temperature phase has been called *α-cristobalite* or metacristobalite; it is stable above 1470° C. and metastable below that temperature. If inversion to tridymite at about 1470° C. does not occur during cooling, the substance inverts very easily to a tetragonal (?) phase (*β-cristobalite*) at temperatures which show an unexplained variation from 275° to 220° C. on cooling and from 198° to 240° C. on heating. For a given crystal the inversion is at a fixed temperature, but for other crystals it seems to depend upon previous heat treatment. *β-Cristobalite* is uniaxial negative with $N_o = 1.487$, $N_\epsilon = 1.484$, $N_o - N_\epsilon = 0.003$. Complex lamellar twinning is common. Colorless. Made from fusion. A rarity, resulting from rapid cooling, in volcanic rocks.

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[27] Arzruni: *Zeit. Kryst.*, XXV, 1895, p. 470.

[28] C. N. Fenner: *Am. Jour. Sci.*, CLXXXVI, 1913, p. 331.

[29] *Comp. Rend.*, CLXXX, 1925, p. 1855.

The moderate temperature phase of SiO_2, called *tridymite*, is hexagonal above 117° (with $c = 1.653$) and orthorhombic below that temperature, with $a : b : c = 0.577 : 1 : 0.954$. It is the stable phase of silica between 870° and 1470° C.; it inverts to quartz below 870° and to cristobalite above 1470°, but these changes are very sluggish and tridymite may exist for long periods as a metastable form. This has permitted the measurement of the fusing point (1670° C.) and the study of the mineral at ordinary temperatures. Tridymite inverts on heating to a phase called *β_1-tridymite* at 117° C., and to another phase called *β_2-tridymite* at 163° C. Both these phases are hexagonal and uniaxial, the change at 163° C. being perhaps from hemihedral to holohedral symmetry. On cooling the inversions show some lag. Crystals of tridymite are usually six-sided basal plates with common wedge-like twinning. Basal plates often show twinning on 110 in sectors as in aragonite and cordierite, the optic plane being normal to the external boundary. Indistinct prismatic cleavage and basal parting. H. = 7. G. = 2.27. Soluble in boiling Na_2CO_3. Tridymite below 117° C. has the optic plane parallel with 100 and the positive acute bisectrix normal to 001. (See Fig. 203.) (+) $2V = 35°$, $N_g = 1.473$ Na, $N_m = 1.469$, $N_p = 1.469$, $N_g - N_p = 0.004$. $N_m = 1.477$ (Longchambon[29]). Colorless. Made from fusion with fluxes. Known in lithophysæ of volcanic rocks and in meteorites.

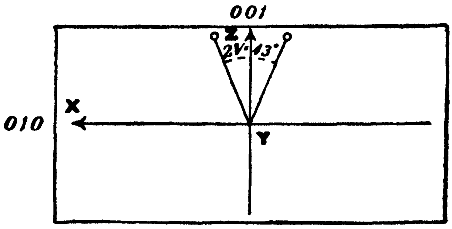

FIG. 203.—Optic orientation of SiO_2, tridymite.

The low temperature phase of SiO_2 is the very common substance known as *quartz*. Crystals hexagonal with $c = 1.09997$, usually prismatic terminated by two rhombohedrons, often twinned. Cleavage absent or very difficult; rhombohedral cleavage may be obtained by sudden cooling which indicates that this cleavage pertains to the high temperature phase of quartz only. H. = 7. G. = 2.65. F. = 7. Insoluble in acids except HF; difficultly attacked by alkalies. Uniaxial positive with $N_o = 1.5419$ C, 1.5442 D, 1.5497 F, $N_e = 1.5509$ C, 1.5533 D, 1.5590 F, $N_e - N_o = 0.0091$. Indices very constant in natural as well as artificial crystals. The refringence decreases very slowly with increase of temperature. The birefringence likewise decreases slowly with increase of temperature, but only to 572° C.; at that temperature there is an abrupt change, and the birefringence thereafter increases. At 572° C. quartz undergoes a reversible inversion from the ordinary trigonal trapezohedral symmetry to hexagonal trapezohedral symmetry, the change involving a 2 per cent increase of volume. Quartz which was formed above 572° C. and has inverted on cooling can be distinguished from quartz which has never been at that temperature by the following features:[30]

(1) Crystal form the presence of the trigonal trapezohedron or other evidence of tetartohedrism being proof of the low temperature form, as in Fig. 204. Simple rhombohedral (pseudocubic as in Fig. 205) rather than prismatic rhombohedral habit is an indication of the high temperature form.

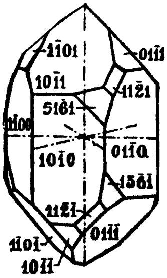

FIG. 204.—A crystal habit of low temperature quartz.

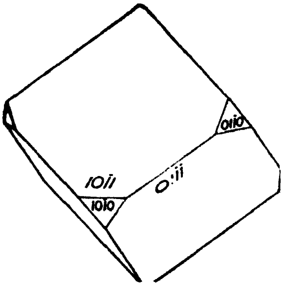

FIG. 205.—A crystal habit of high temperature quartz.

(2) Character of the twinning, especially as shown by etch figures on the basal pinacoid; in the low temperature form the twinning is simple and regular; in that which has inverted, it is irregular in small patches bearing no relation to the crystal form.

(3) Intergrowths of right- and left-handed quartz are more frequent and more regular in the low temperature form.

(4) Inversion produces a shattering due to a distinct change of volume.

Quartz undergoes a second inversion at 870° C to tridymite and a third at 1470° C. to cristobalite, but these are very sluggish and occur only under especially favorable conditions. The reverse changes are possible, but are equally sluggish.

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[30] F. E. Wright: *Am. Jour. Sci.*, CLXXVII, 1909, p. 438.

SiO_2 glass has G. = 2.19; isotropic with $N = 1.4588$. The natural substance, called *lechatelierite*, is produced when lightning strikes quartz sand and fuses tiny tubes (*fulgurites*) in it. Ignition of silica hydrogel or chemically precipitated silica changes it to cristobalite with $N = 1.48–1.485$.

A fibrous variety of SiO_2, called *chalcedony*, has the same crystal structure as quartz,[31] but has H. = 6 and G. = 2.55–2.63, apparently with $N_o = 1.537$ (1.533–1.539), $N_e = 1.530$, $N_o - N_e = 0.007$, but the sign is uncertain and the substance may be biaxial, since the fibers in some cases seem to have ± elongation, parallel to Y, or extinction inclined at 29°.

SeO_2 is tetragonal or hexagonal[32] when crystallized in selenium. G. = 3.96. Acicular. Uniaxial and positive. $N > 1.76$, $N_e - N_o =$ strong. Another phase is monoclinic.

GeO_2 crystallizes from aqueous solution in forms which are apparently orthorhombic; when prepared by hydrolyzing $GeCl_4$ with water[33] GeO_2 has $N = 1.650$ Na. When fused to a glass[33] GeO_2 has G. = 3.638, H. = 4.5–5, and $N = 1.6030$ C, 1.6070 D, 1.6176 F. Colorless.

7. OXIDES OF TRIVALENT AND MONOVALENT ELEMENTS

$LiAlO_2$ forms hexagonal or octagonal plates[34] or (rhombic?) grains[35] with G. = 2.554 and $N_1 = 1.604$, $N_2 = 1.615$, $N_g - N_p = 0.012$. No interference figure seen. Colorless. Made from fusion and melts at 1900°–2000° C.

8. ANHYDROUS OXIDES OF TRIVALENT AND DIVALENT ELEMENTS

The compounds of this division (and the next) may be considered aluminates, ferrites, chromates, etc., of magnesium, iron, zinc, or manganese, but the corresponding acids are hypothetical and X-ray work suggests that these substances are double oxides.

$MgAl_2O_4$ is isometric[36] in octahedral crystals (see Fig. 206), sometimes modified by 110. Twinning common on 111. Cleavage parallel to 111, quite indistinct. H. = 8. G. = 3.6. F. = 2135° C. Slowly soluble in H_2SO_4. Isotropic with N = 1.73. The pure substance[37] has N = 1.7161 (623), 1.7190 (578), 1.7322 (436). It may take as much as 75 mol. per cent $Al_2Al_4O_9$ (to 25 per cent $Mg_2Al_4O_8$) in crystal solution[37] and then N = 1.7261 (623), 1.7288 (578), 1.7428 (436). With about[38] 50 mol. per cent $Al_2Al_4O_9$, N = 1.723 Li, 1.727 Na, 1.736 Tl. With 9 per cent $MgFe_2O_4$ in crystal solution N = 1.76 Na. Apparently SiO_2 may enter into crystal solution[36] in $MgAl_2O_4$ in limited amount; then N may be as low as 1.718. Colorless or blue or red from impurities; blue varieties are said to have an index higher than red types.[39] Pure spinel glass[40] has N = 1.67–1.68. Spinel is often birefringent from strain. Made from fusion for use as a gem.

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[31] Washburn and Navias: *Proc. Nat. Acad. Sci.*, VIII, p. 1.

[32] L. T. Brownmiller: *Am. Mineral.*, XII, 1927, p. 43.

[33] L. M. Dennis: *Jour. Phys. Chem.*, XXX, 1926, p. 1510.

[34] F. M. Jaeger and A. Simek: *Proc. Akad. Wet. Amst.*, XVII, 1914, p. 268.

[35] Z. Weyberg: *Cent. Min.*, 1906, p. 645.

[36] G. A. Rankin and H. E. Merwin: *Jour. Am. Chem. Soc.*, XXXVIII, 1916, p. 568

$ZnAl_2O_4$ is isometric[40] in octahedral crystals, sometimes modified by 110 or 100. G. = 4.58. N = 1.805. Colorless.

$CoAl_2O_4$ is isometric[20] with N > 1.78 red, N = 1.74 blue. This is the "cobalt blue" pigment of commerce.

$MgFe_2O_4$ is isometric and granular or octahedral without cleavage. Dissociates somewhat at high temperature and begins to melt at 1750° C. G. = 4.6. Soluble in HCl. Isotropic[41] with N = 2.34 ± 0.02 Li, 2.39 Na; the index varies about ± 0.02, due to crystal solutions. Color red.

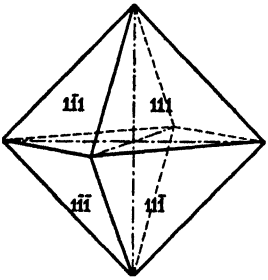

Fig. 206.—A crystal habit of $MgAl_2O_4$.

$ZnFe_2O_4$ is isometric with octahedral crystal habit. G. = 5.3. Isotropic[41] with N = 2.31 ± .02 Li.

$CdFe_2O_4$ is isometric[41] with G. = 5.8. Isotropic with N = 2.39 ± .02 Li.

$Ca_3Al_2O_6$ is isometric[42] with poor 111 or 110 cleavage and H. = 6. It dissociates at 1535° C. Isotropic with N = 1.710 Na. Colorless. Formed from the glass at about 1500° C. It can take about 2 per cent Fe_2O_3 in crystal solution[18] replacing Al_2O_3; then it has N = 1.715.

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[37] F. Rinne: *N. J. Min.*, LVIII, A, 1928, p. 43.

[38] R. Brauns: *Cent. Min.*, 1927, A, p. 265.

[39] P. Gaubert: *Bull. Soc. Fr. Min.*, L, 1927, p. 504.

[40] P. Gaubert: *C. R. Cong. Soc. Sav. Sci.*, 1925.

[41] E. Posnjak: *Am. Jour. Sci.*, CCXIX, 1930, p. 67. H. E. Merwin: *Am. Jour. Sci.*, XXI, 1931, p. 145.

[42] G. A. Rankin and F. E. Wright: *Am. Jour. Sci.*, 189, 1915, p. 1.

$Ca_5Al_6O_{14}$ is isometric [42] with no distinct cleavage. H. = 5. F. = 1455° C. Isotropic with N = 1.608 Na. Colorless. The glass has N = 1.662.[43] Formed from fusion. It can take about 2 per cent Fe_2O_3 in crystal solution,[18] replacing Al_2O_3; then it has N = 1.613. An unstable phase is fibrous and probably orthorhombic with H. = 5. The optic plane is parallel to the negative elongation. (—?) 2V = large. $N_g = 1.692, N_m = ?, N_p = 1.687, N_g - N_p = 0.005$. Usually green with X = blue green, Z = olive green and X < Z.

$CaFe_2O_4$ is tetragonal or hexagonal.[44] It dissociates at 1216° C. Crystals long acicular. Uniaxial negative with $N_o = 2.465$ Li, 2.58 Na, $N_e = 2.345$ Li, 2.43 Na, $N_o - N_e = 0.15$ Na. Color black in mass and deep red in powder like hematite. Formed from the glass at 1190° C. It may take as much as 10 per cent $CaAl_2O_4$ in crystal solution;[45] then it has $N_o = 2.25$ Li, N_e 2.13, $N_o - N_e = 0.12$.

$Ca_3Al_{10}O_{18}$ is probably tetragonal;[44] no distinct cleavage and crystals equant. H. = 6.5. Fuses at 1720° C. Uniaxial positive with $N_o = 1.617, N_e = 1.652, N_e - N_o = 0.035$. May be slightly biaxial. Colorless. Formed from fusion. An unstable phase is probably orthorhombic in prisms with prismatic cleavage. H. = 5.5–6. The optic plane is parallel to the positive elongation. (−) 2V = 35°, $\rho > v$ strong. $N_g = 1.674$, $N_m = 1.671$, $N_p = 1.662$, $N_g - N_p = 0.012$. Colorless. Formed from the chilled melt.

$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$ forms prismatic grains [45] with a very small extinction angle. G. = 3.77. Shows some multiple twinning. Fuses at 1415° C. (−) 2V = moderate. $N_g = 2.04$ Li, 2.08 (578), $N_m =$ = 2.01 Li, 2.05 (578), $N_p = 1.96$ Li, 1.98 (578), $N_g - N_p = 0.08$ Li, 0.10 (578). Marked color with X = yellow-brown, Z = brown. Forms a complete series of crystal solutions with $2CaO \cdot Fe_2O_3$ with a narrow melting range. May take a little MgO (less than 1 per cent) in crystal solution, which makes the color darker and almost opaque for Z.

$Ca_2Fe_2O_5$ is of low symmetry;[44] it dissociates at 1436° C. to CaO and liquid; no crystals nor cleavages found. (+) 2V = moderate. $N_g = 2.29$ Li, $N_m = 2.22$ Li, $N_p = 2.20$ Li, 2.25 Na, $N_g - N_p = 0.09$ Li. Color black; yellowish brown in section with X > Y = Z. Formed from the glass at 1000–1400° C.

[43] Is this an error for 1.562?

[44] R. B. Sosman and H. E. Merwin: *Jour. Wash. Acad. Sci.*, VI, 1916, p. 532.

[45] Hansen, Brownmiller and Bogue: *Jour. Am. Chem. Soc.*, L, 1928, p. 396.

$CaAl_2O_4$ is orthorhombic or monoclinic.[46] Prismatic to fibrous. Distinct 110 cleavage. Pseudohexagonal twinning on 130. G. = 3.67. H. = 6.5. F. = 1600° C. Soluble in HCl. Attacked by water. The optic plane is 010; X = *c*. (−) 2V = 36° (56° Carstens). N_g = 1.663, N_m = 1.655, N_p = 1.643, $N_g - N_p$ = 0.020. Colorless. Formed from fusion. It may take as much as 15 per cent $CaFe_2O_4$ in crystal solution[45] then it has N_g = 1.72 ±, N_m = ?, N_p = 1.70 ±, $N_g - N_p$ = 0.02 ±.

9. HYDROUS OXIDES OF TRIVALENT AND DIVALENT ELEMENTS

$Ca_3Al_2O_6 \cdot 6H_2O$ is stable from 25° C. to 100° C. It is isometric with G. = 2.52. Crystals trapezohedral,[47] as shown in Fig. 207, or, less commonly, cubic or dodecahedral. Isotropic with N = 1.604 D. Colorless.

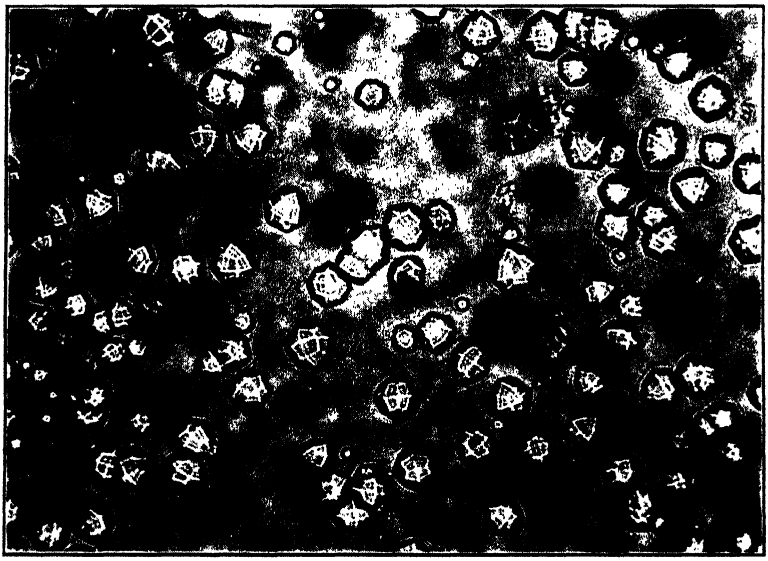

FIG. 207.—Trapezohedral crystals of $Ca_3Al_2O_6 \cdot 6H_2O$. Photomicrograph by Dr. V. A. Vigfusson.

$Ca_3Al_2O_6 \cdot 8\text{-}12H_2O$ is hexagonal[47] in basal plates, needles or spherulites. Uniaxial negative. Colorless. Water content variable;

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[46] G. A. Rankin and F. E. Wright: *Am. Jour. Sci.*, CLXXXIX, 1915, p. 1. G. A. Rankin: *Jour. Am. Chem. Soc.*, XXXVIII, 1916, p. 568. C. W. Carstens: *Zeit. Kryst.*, LXIII, 1926, p. 473.

[47] T. Thorvaldson, N. S. Grace and V. A. Vigfusson: *Can. Jour. Res.*, I, 1929, p. 201.

with $8H_2O$, G. = 2.13, N_o = 1.538 D, N_e = 1.520, $N_o - N_e$ = 0.018. With 10.5 H_2O, G. = 2.04, N_o = 1.530, N_e = 1.510, $N_o - N_e$ = 0.020. With $12H_2O$, N_o = 1.527, N_e = 1.505, $N_o - N_e$ = 0.022.

$4CaO \cdot Al_2O_3 \cdot 12H_2O$ forms plates[48] or needles with positive elongation. N_g = 1.532, N_m = ?, N_p = 1.505, $N_g - N_p$ = 0.027. Colorless. [Apparently the same as $Ca_3Al_2O_6 \cdot 12H_2O$ – A.N.W.]

VI. CARBONATES

This division includes all artificial carbonates whose optic properties have been measured. Nitrates are added because some of them are crystallographically very similar to carbonates. Finally, nitrites and also chlorates, bromates and iodates are included.

1. ANHYDROUS CARBONATES OF MONOVALENT BASES

$NaLiCO_3$ is hexagonal[1] in prismatic crystals. Uniaxial negative with N_o = 1.538, N_e = 1.406, $N_o - N_e$ = 0.132. Colorless.

NH_4HCO_3 is orthorhombic with $a : b : c$ = 0.673 : 1 : 0.400. Crystals equant to columnar prismatic with very perfect 110 cleavages at 68°. H. = 1.5. G. = 1.57. F. = 5.5, but largely volatile. The optic plane is 010; X = *a*. (–) 2V = 41° 38′, $\rho < v$, weak. N_g = 1.5545, N_m = 1.5358, N_p = 1.4227, $N_g - N_p$ = 0.1318 Na. Colorless. Made from H_2O solution in closed vessels. The natural substance, called *teschemacherite*, occurs in guano deposits.

$KHCO_3$ is monoclinic with $a : b : c$ = 2.677 : 1 : 1.312, β = 76°35′. Crystals orthodomatic (101, 001, 201, 100, 110) or 001 tablets with 100, 001 and 101 cleavages. G. = 2.16. F. = easy. Soluble in water. The optic plane is 010; $X \wedge c$ = +30°. (–) 2V = 81½°. Indices[2]:—N_g = 1.569 C, 1.578 D, 1.581 F. N_m = 1.479 + C, 1.482 D, 1.487 + F, N_p = 1.379 C, 1.380 D, 1.383 F, $N_g - N_p$ = 0.193. Colorless. Made by adding CO_2 to a solution of K_2CO_3. The natural substance, called *kalicinite*, is very rare.

$NaHCO_3$ (*baking soda*) is monoclinic with $a : b : c$ = 0.765 : 1 : 0.358, β = 86° 41′. Crystals 010 tablets bounded by 110, 111, and $11\bar{1}$, see Fig. 208, often twinned on 101; perfect 101, distinct 111 and imperfect 100 cleavages. G. = 2.22. The optic plane is 010; $X \wedge$ elong.

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[48] L. S. Wells: *Bur. Stand. Jour. Res.* I, 1928, p. 951.

[1] W. Eitel and W. Skaliks: *Zt. anorg. Chem.*, CLXXXIII, 1929, pp. 263–286; W. Skaliks: *Verh. k. Wilhelm Inst. Silikatfor.*, III, 1930, *Anhang*.

[2] H. E. Merwin: *Int. Crit. Tab.*, VII, 1930, p. 27.

$= +20°$ (Larsen); $X \wedge c = +27.5°$ (Robson).[3] This extinction angle being about half the angle between the c axes in 101 twins, the substance may be recognized by the peculiar condition that both parts of the twin go to extinction simultaneously (Robson[3]). (−) $2V = 75°$; $\rho > v$. $N_g = 1.586$, $N_m = 1.500$, $N_p = 1.380$, $N_g - N_p = 0.206$.

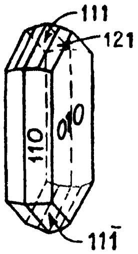

FIG. 208.—A crystal habit of NaHCO$_3$.

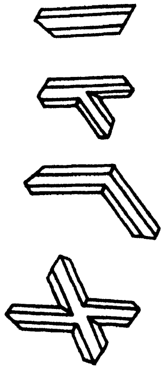

FIG. 208a.—Drawings of NaHCO$_3$ crystals from a photomicrograph made by R. B. MacMullin.

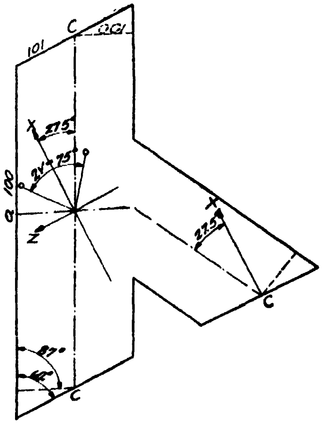

FIG. 208b.—Optic orientation of NaHCO$_3$ twin.

(Larsen); $N_g = 1.582$, $N_m = 1.500$, $N_p = 1.376$, $N_g - N_p = 0.206$ (Merwin).[3a] Colorless, white. The natural substance is rare; it has been named *nahcolite*.[4]

Na$_2$CO$_3$ from fusion shows lamellar twinning.[4a] (−) $2V = 34° \pm 3°$, $N_g = 1.546$, $N_m = 1.535$, $N_p = 1.415$, $N_g - N_p = 0.131$. Colorless.

K$_2$CO$_3$ from fusion shows lamellar twinning with very oblique extinction.[4a] (−) $2V = 35° \pm 5°$, $N_g = 1.541 \pm .002$, $N_m = 1.531 \pm .002$, $N_p = 1.426 \pm .004$, $N_g - N_p = 0.115 \pm .006$. Colorless.

Li$_2$CO$_3$ is monoclinic with $a : b : c = 1.672 : 1 : 1.244$, $\beta = 65° 35'$. Crystals prismatic with perfect 001 and distinct 101 cleavages. Common twinning on 100. G. = 2.1. Soluble in water. The optic plane is normal to 010; $X \wedge c =$ nearly 0°. (−) $2E = 24° \pm$; $2V = 15° \pm$; $N_g = 1.572$, $N_m = 1.567$, $N_p = 1.428$, $N_g - N_p = 0.144$ Na. Colorless. Made from fusion or by heating a saturated solution.

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[3] H. L. Robson: personal communication, Dec. 3, 1930.

[3a] Personal communication, Mar. 25, 1931.

[4] F. A. Bannister: *Mineral. Mag.*, XXII, 1929, p. 60.

[4a] Properties determined by H. E. Merwin; personal communication, Mar. 25, 1931.

2. HYDROUS CARBONATES OF MONOVALENT BASES

$Na_2CO_3 \cdot H_2O$ is orthorhombic with $a : b : c = 0.827 : 1 : 0.809$. Crystals varied, 100 or 001 tablets or columnar parallel to a with difficult 010 cleavage. H. = 1.5. G. = 2.26 (Pabst). F. = 1.5. Soluble in water. The optic plane is 001; $X = a$ (Lacroix); $X = b$ (Merwin).[4a] $(-)$ $2V = 48°$, $\rho < v$ weak. $N_g = 1.524$, $N_m = 1.506$, $N_p = 1.420$, $N_g - N_p = 0.104$ (Larsen); $N_g = 1.525$, $N_m = 1.509$, $N_p = 1.420$ (Merwin).[4a] Colorless or white. Made from H_2O solution at about 30° C. The natural substance, called *thermonatrite*, is an efflorescence in arid regions.

$Ag_2CO_3 \cdot 4NH_3 \cdot H_2O$ is orthorhombic[5] with $a : b : c = 0.577 : 1 : 0.768$, and pseudohexagonal. Crystals prismatic or pyramidal. Perfect 010 and 021 cleavages with distinct 001 and 110 partings. Twinning on 110 very common. The optic plane is 010; $Z = c$. $(+)$ $2E = 17°$, $(2V = 10°)$, $\rho < v$ strong, the substance being uniaxial in the extreme red and having $2E = 36°$ for 435 mμ. $N_g = 1.68$, $N_p = 1.66$, $N_g - N_p = 0.023$ Na ($N_g - N_p = 0.0175$ for 435 mμ). Colorless. Unstable in air.

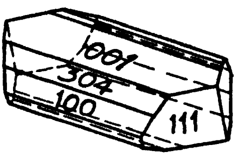

FIG. 209.—A crystal habit of $HNa_3(CO_3)_2 \cdot 2H_2O$.

$Na_2CO_3 \cdot 2\frac{1}{2}H_2O$ is orthorhombic with $a : b : c = 0.794 : 1 : 0.439$. Crystals acicular prismatic (often in sheaves) terminated by a pair of planes making an angle of 134°. G. = 2.05. Negative elongation with $X = c$. $(-)$ $2V$ = large.[6] $N_g = 1.547$, $N_m = 1.492$, $N_p = 1.435$, $N_g - N_p = 0.112$. Colorless. Formed from evaporation of H_2O solution of Solvay soda at 18° to 25° C.

$Na_2CO_3 \cdot 10H_2O$ is monoclinic with $a : b : c = 1.483 : 1 : 1.400$, $\beta = 58° 52'$. Crystals 010 tablets with distinct 001 and imperfect 010 cleavages. Twinning on 100. H. = 1–1.5. G. = 1.46. F. = 1. Dehydrates very easily. The optic plane is normal to 010; $Z \wedge c = +41°$. $(-)$ $2V = 71°$, $\rho > v$ weak with weak crossed dispersion. $N_g = 1.440$, $N_m = 1.425$, $N_p = 1.405$, $N_g - N_p = 0.035$. Colorless. Made from H_2O solution. The natural substance, called *natron*, is very rare.

$HNa_3(CO_3)_2 \cdot 2H_2O$ is monoclinic[7] with $a : b : c = 2.843 : 1 :$

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[5] *Bull. Soc. Fr. Min.*, XLVI, 1923, p. 20.

[6] A. Pabst: *Am. Mineral.*, XV, 1930, p. 69. Larsen's data for "trona" from Vesuvius may apply to this substance—see *U. S. Geol. Surv. Bull.*, 679, 1921, p. 146.

[7] Data of Zepharovich given above. Buttgenbach (*Ann. Soc. Geol. Belg.*, XLII, 1919, p. 93) gives: $Z \wedge c = 43°$ and $N_g - N_p$ between 0.035 and 0.055.

2.949, $\beta = 76° 31'$. Crystals 001 tablets or elongated parallel to *b* with perfect 100 cleavage, as in Fig. 209. H. = 3. G. = 2.13. F. = 1.5. The optic plane and X are normal to 010; $Y \wedge c = +6°$. (−) $2V = 72°$, $\rho < v$ marked. $N_m = 1.507$, $N_g - N_p$ = strong. Colorless. Made from H_2O solution containing much NaCl and Na_2SO_4 at 50°–85° C. The natural substance, called *trona*, is an efflorescence or lake deposit in very arid regions.

3. ANHYDROUS CARBONATES OF DIVALENT BASES

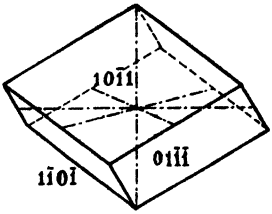

FIG. 210.

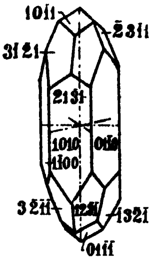

FIG. 211.

FIGS. 210, 211.—Crystal habits of $CaCO_3$, calcite.

$CaCO_3$ has three crystal phases;[8] the most stable low temperature phase is trigonal with $c = 0.854$. Crystals varied, often rhombehedral with perfect $10\bar{1}1$ cleavage. See Figs. 210 and 211. H. = 3. G. = 2.71. F. = 7, but dissociates at 900° C. Under pressure of 110 atmospheres or more of CO_2, $CaCO_3$ fuses at 1290° C. Soluble in cold HCl with effervescence. Uniaxial negative with $N_o = 1.6544$ C, 1.6585 D, 1.6678 F, $N_e = 1.4846$ C, 1.4864 D, 1.4908 F, $N_o - N_e = 0.1721$ D. Colorless. Made from the bicarbonate solution at ordinary temperature. The natural substance, called *calcite*, is not only the chief constituent of limestone and marble, but also common in veins and, as an alteration product, in igneous rocks.

FIG. 212.—Photomicrograph of $CaCO_3$, calcite, showing three directions of cleavage.

Another phase of $CaCO_3$ is unstable at all temperatures (above 0° at least), but may persist for long periods at ordinary temperature as a metastable form (λ–$CaCO_3$). It is orthorhombic with $a:b:c = 0.623 : 1 : 0.720$. Crystals prismatic to fibrous with distinct 010 and 110 cleavages. Twinning on 110 as in Fig. 213 often in pseudohexagonal groups, as in Fig. 214. H = 3.5–4. G. = 2.88. Very soluble in cold HCl with effervescence. The optic plane is 100: X = c. (−) $2V = 18° 11'$ Na, $\rho < v$ weak. N_g = 1.6815 C, 1.6854 D, 1.6947 F, N_m = 1.6772 C, 1.6810 D, 1.6910 F, N_p = 1.5279 C, 1.5300 D, 1.5346 F, $N_g - N_p$ = 0.1554 D. If made from a solution containing sulphate it is impure and then: N_g = 1.650 − 1.673, N_p = 1.510 − 1.520. A similar substance [9] is reported from the interaction of $CaCl_2$ and Na_2CO_3. Colorless. Made from bicarbonate solution at about 90° C. The natural substance, called *aragonite*, is the chief constituent of many shells and is found in lake deposits, etc.

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[8] J. Johnston, H. E. Merwin and E. D. Williamson: *Am. Jour. Sci.*, CXCI, 1916, p. 473. Also H. E. Merwin: personal communication, Mar. 8, 1930.

The least stable phase of $CaCO_3$, known as μ–$CaCO_3$, is hexagonal with G. = 2.54, as determined on aggregates. Crystals basal plates or aggregates. Uniaxial positive with N_o = 1.550, N_e = 1.650, $N_e - N_o$ = 0.100. Colorless. Aggregates may form which give an apparently biaxial interference figure with 2E = 35°–40°, and the optic plane parallel to the external sides of the triangular groups. In such aggregates the indices seem to be about 0.01 lower than their true values. The occurrence of this form in nature is doubtful. "*Vaterite*" is perhaps a spherulitic variety of μ–$CaCO_3$.

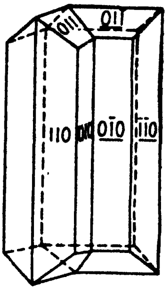

FIG. 213.—$CaCO_3$, aragonite twinned on 110.

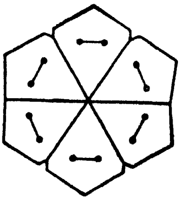

FIG. 214.—Cross section of pseudohexagonal twin of $CaCO_3$, aragonite.

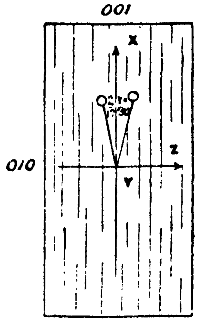

FIG. 215.—Optic orientation of $CaCO_3$, aragonite.

$PbCO_3$ is orthorhombic with $a : b : c = 0.610 : 1 : 0.723$. Crystal habit prismatic. Twinning common, sometimes pseudohexagonal on 110. Distinct 110 and 021 cleavages. H. = 3-3.5. G. = 6.57. F. = 1.5. Soluble in dilute HNO_3 with effervescence. The optic plane is 010 and the acute bisectrix X is parallel with the prismatic elongation.[10] (−) $2V = 8° 34'$ (natural crystal), $N_g = 2.08$, $N_m = 1.81 \pm$, $N_p = 1.80$, $N_g - N_p = 0.28$. Colorless. Often present in commercial "white lead." The natural substance is called *cerussite*.

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[9] *Jour. Geol. Soc. Tokyo*, XXXVI, 1929, p. 7.

4. HYDROUS CARBONATES OF DIVALENT BASES

$Pb_3(OH)_2(CO_3)_2$ is hexagonal in basal plates with $c = 1.419$. Soft. Perfect 0001 cleavage. G. = 6.14. Soluble in dilute HNO_3. Uniaxial negative[10] with $N_o = 2.09$, $N_e = 1.94$, $N_o - N_e - 0.15$. Colorless. This is the pigment called "white lead." The natural mineral is called *hydrocerussite*.

$MgCO_3 \cdot 3H_2O$ is orthorhombic with $a : b : c = 0.645 : 1 : 0.457$. Crystals long prismatic, vertically striated, with perfect 110 and poor 001 cleavages. H. = 2.5. G. = 1.85. Soluble in cold HCl with effervescence. The optic plane[11] is 001; $X = a$. Optic axes nearly normal to 110 cleavages. (−) $2V = 53°$, $\rho > v$ weak. $N_g = 1.526$ Na,[12] $N_m = 1.501$, $N_p = 1.412$ (corrected),[11] $N_g - N_p = 0.114$. Ballo[13] gives $N = 1.474$ to 1.557. Colorless. The natural substance, called *nesquehonite*, is found rarely in coal mines.

$CaCO_3 \cdot 6H_2O$ is monoclinic with $a : b : c = 1.02 : 1 : ?$, $\beta = 72°$? Crystals basal plates or stout prisms. G. = 1.75 (1.82?) The optic plane[14] is 010; $Z \wedge c = +17°$ with distinct inclined dispersion. (−) $2V = 38°$, $N_g = 1.545$, $N_m = 1.535$, $N_p = 1.460$, $N_g - N_p = 0.085$. Colorless. Formed at 0° C. from H_2O solution containing KOH; changes to calcite easily.

$CaCO_3 \cdot 5H_2O$(?) is formed[14] (by partial dehydration?) from $CaCO_3 \cdot 6H_2O$ at room temperature. Formed under ether the indices are $N_g = 1.605$, $N_p = 1.530$, $N_g - N_p = 0.075$; formed under benzol, the indices are $N_g = 1.63$, $N_p = 1.54$, $N_g - N_p = 0.09$; changes to calcite very easily.

$MgCO_3 \cdot 5H_2O$ is monoclinic[15] with $a : b : c = 1.632 : 1 : 0.968$, $\beta = 78° 11'$. Crystals stalactitic with distinct 001 cleavage. H. = 2.5. G. = 1.73. Soluble in cold HCl with effervescence. The optic plane is normal to 010; $Z \wedge c$ = small. (+) $2V = 60° 37'$, $N_g = 1.508$

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[10] H. E. Merwin: *Proc. Am. Soc. Test. Mat., XVII*, 1917, Pt. 2.

[11] G. Césaro: *Bull. Acad. Roy. Cl. Sci., Bruxelles*, 1910, p. 234.

[12] S. L. Penfield: *Am. Jour. Sci.*, CXXXIX, 1890, p. 121.

[13] *Mineral Abst.*, I, 1922, p. 317.

[14] H. E. Merwin: *Am. Jour. Sci.*, CXCI, 1916, p. 492.

[15] G. Césaro: *Bull. Acad. Roy. Cl. Sci., Bruxelles*, 1910, p. 234. E. Poitevin: *Am. Mineral.*, IX, 1924, p. 225.

(calc.), $N_m = 1.470$, $N_p = 1.457$ (calc.), $N_g - N_p = 0.051$ (calc.). Colorless. The natural substance, called *lansfordite*, occurs rarely as stalactites in coal mines.

5. ANHYDROUS CARBONATES OF DIVALENT AND MONOVALENT BASES

$Na_2Ca(CO_3)_2$ is hexagonal[1] in basal plates with perfect basal cleavage. G. = 2.54. Fuses at 812° C. in CO_2 gas. Uniaxial negative with $N_o = 1.547$, $N_e = 1.504$, $N_o - N_e = 0.043$. May be biaxial of small optic angle under strain. Stable in air. Colorless.

$K_2Ca(CO_3)_2$ is hexagonal[1] in basal plates with distinct basal cleavage. G. = 2.465. Fuses at 813° C. in CO_2 gas. Uniaxial negative with $N_o = 1.530$, $N_e = 1.48 \pm$, $N_o - N_e = 0.05 \pm$. Colorless.

$Na_2Mg(CO_3)_2$ is hexagonal[1] with $c = 3.33$ and distinct prismatic cleavage. G. = 2.734. Fuses at 677° C. under a pressure of 1240 kg/cm.[2] Uniaxial negative with $N_o = 1.594$, $N_e = 1.54$, $N_o - N_e = 0.054$. Colorless.

$K_2Mg(CO_3)_2$ is probably hexagonal[1] with prismatic cleavage. G. = 2.671. Uniaxial negative with $N_o = 1.597$, $N_e = 1.47$, $N_o - N_e = 0.127$. Colorless. Forms a glass from fusion which has G. = 2.39 and N = 1.496.

6. CARBONATES OF HEXAVALENT AND DIVALENT BASES

$(NH_4)_4UO_2(CO_3)_3$ is monoclinic with $a : b : c = 0.964 : 1 : 0.867$, $\beta = 80° 43'$. Crystals prismatic with perfect 001 cleavage. G. = 2.77. (−) 2V[16]= ?, $N'_g = 1.625$, $N_m = ?$, $N'_g - N'_p = 0.025$. Color yellow.

7. IODATES, BROMATES AND CHLORATES[17]

$NaClO_3$ is isometric and tetartohedral; crystals cubic or tetrahedral in habit without cleavage. See Figs. 216, 217. Penetration twins common on 100, as in Fig. 218. G. = 2.49. Soluble in water. Isotropic with N = 1.5127 C, 1.5151 D, 1.5216 F. Rotates the plane of polarization for 1 mm. of thickness 2.3° B, 3.1° D, 4.6° F. Colorless. Formed from H_2O solution.

$NaBrO_3$ is isometric and tetartohedral; crystals tetrahedral, etc.

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[16] Optic data from Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275), measured on "ammonium uranium carbonate" of unknown formula.

[17] Recent X-ray work affords a suggestion that chlorates, and presumably bromates and iodates, are crystallographically closely related to halides.

G. = 3.3. Soluble in water. Isotropic with N = 1.6117 for 672 $m\mu$,[18] 1.617 for 579 $m\mu$; 1.6268 for 492 $m\mu$; N = 1.5943 Na (Craw);[19] some crystals more or less birefringent under certain conditions. All crystals rotate the plane of polarization, a thickness of 1 mm. producing a rotation of 1.4° B, 2.1° D, and 3.75° F. Colorless. Formed from H_2O solution.

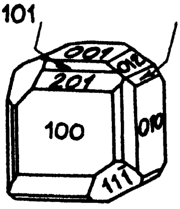

Fig. 216.

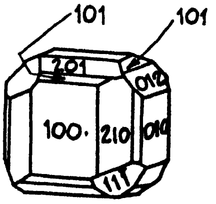

Fig. 217.

Figs. 216, 217.—Right- and left-handed crystals of $NaClO_3$.

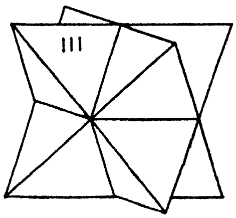

Fig. 218.—Penetration spinel twin of $NaClO_3$.

$Mg(BrO_3)_2 \cdot 6H_2O$ is isometric and octahedral with G. = 2.29 and N = 1.5139 Na.

$Zn(BrO_3)_2 \cdot 6H_2O$ is isometric and octahedral with G. = 2.51 and N = 1.5452 Na.

$AgBrO_3$ is tetragonal with c = 0.941. Crystals columnar prismatic or pyramidal with imperfect 110 cleavages. G. = 5.1–5.2. Uniaxial positive with N_o = 1.8466 Na, 1.860 (green), N_e = 1.920 Na, 1.9405 (green), $N_e - N_o$ = 0.0734 Na. Color white.

KIO_4 is tetragonal, forming pyramidal crystals with G. = 3.62. It is stable to 200° C. but loses oxygen at 300° to form KIO_3. Uniaxial positive [19a] with N_o = 1.6151 C, 1.6205 D, 1.6346 F, N_e = 1.6416 C, 1.6479 D, 1.6651 F, $N_e - N_o$ = 0.0274 D.

$Ba(ClO_4)_2 \cdot 3H_2O$ is hexagonal.[19b] Crystals prismatic, hygroscopic. Uniaxial negative with N_o = 1.5330, N_e = 1.5323, $N_o - N_e$ = 0.0007.

$Co(ClO_4)_2 \cdot 6H_2O$ [20] is hexagonal. Crystals long prismatic. Uniaxial negative with N = 1.55 ±, $N_o - N_e$ = 0.018. Color pink with X = deep pink, Z = pale pink, slightly yellowish.

$Ni(ClO_4)_2 \cdot 6H_2O$ [20] is hexagonal. Crystals long prismatic. Uniaxial negative with N = 1.55 ±, $N_o - N_e$ = 0.016. Color greenish blue with X = dark bluish green, Z = green.

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[18] *N. Jahrb. Min. Beil. Bd.* XXIX, 1910, p. 64.

[19] *Zeit. phys. Chem.*, XIX, 1896, p. 276.

[19a] H. E. Merwin: *Int. Crit. Tables*, VII, 1931, p. 27.

[19b] P. Wulff: *Zeit. Kryst.*, LXXVII, 1931, p. 84. Groth gives for the salt with $3H_2O$ c = 1.328; crystals prismatic with negative very weak birefringence—probably the same.

[20] R. Sabot: *Bull. Soc. Fr. Min.*, XXXIV, 1911, p. 144.

$Sr(ClO_3)_2$[21] is orthorhombic with *a* : *b* : *c* = 0.916 : 1 : 0.597. Crystals pyramidal. The optic plane is 100; X = *c*, (−) 2V = 72° 21′, $\rho > v$. N_g = 1.6210 B, 1.6257 D, 1.6337 F, N_m = 1.6002 B, 1.6047 D, 1.6116 F, N_p = 1.5636 B, 1.5670 D, 1.5717 F, $N_g - N_p$ = 0.0587 D. Colorless.

$NaClO_4$ is orthorhombic[21a] and apparently isomorphous with $CaSO_4$. G. = 2.50. Optic orientation unknown. (+) 2V = small. N_g = 1.4730, N_m = 1.4617, N_p = 1.4606, $N_g - N_p$ = 0.0124. Colorless.

$KClO_4$ is orthorhombic[22] with *a* : *b* : *c* = 0.781 : 1 : 1.281; crystals thick 001 tablets as in Fig. 219 with perfect 001 and 110 cleavages.

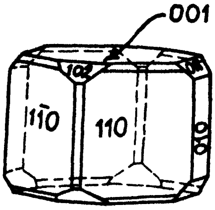

FIG. 219.—A crystal habit of $KClO_4$. (After Tutton.)

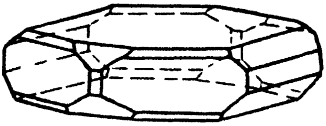

FIG. 220.—A crystal habit of $CsClO_4$. (After Tutton.)

G. = 2.524. The optic plane is 100; Z = *b*. (+) 2V = 50° 15′ C, 49° 48′ D, 48° 48′ F., $\rho > v$ distinct. N_g = 1.4750 C, 1.4769 D, 1.4812 F, N_m = 1.4718 C, 1.4737 D, 1.4779 F, N_p = 1.4712 C, 1.4731 D, 1.4774 F, $N_g - N_p$ = 0.0038 D. Colorless. Made by reaction of K_2SO_4 with $Ba(ClO_4)_2$. Miscible in all proportions with $KMnO_4$.

$RbClO_4$ is orthorhombic[22] with *a* : *b* : *c* = 0.796 : 1 : 1.288; crystals thick basal tablets to prismatic and apparently sphenoidal with distinct 001 and 110 cleavages. G. = 3.014. The optic plane is 100; Z = *b*. (+) 2V = 55° 12′ C., 55° 4′ D, 54° 33′ F, $\rho > v$ weak. N_g = 1.4715 C, 1.4731 D, 1.4774 F, N_m = 1.4684 C, 1.4701 D, 1.4742 F, N_p = 1.4674 C, 1.4692 D, 1.4732 F, $N_g - N_p$ = 0.0039 Na. Colorless. Made by reaction of Rb_2SO_4 with $Ba(ClO_4)_2$.

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[21] *Tables Ann. Constantes*, IV, 1922, p. 1067.

[21a] P. Wulff: *Zeit. Kryst.*, LXXVII, 1931, p. 84.

[22] A. E. H. Tutton: *Proc. Roy. Soc.*, A, 111, 1926, p. 462. P. Wulff (*Zeit. Elektrochem.*, XXXIV, 1928, p. 611) gives N_g = 1.4761 D, N_m = 1.4719, N_p = 1.4726, $N_g - N_p$ = 0.0035 for $KClO_4$ and N_g = 1.4870 D, N_m = 1.4833, N_p = 1.4826, $N_g - N_p$ = 0.0044 for NH_4ClO_4. H. E. Merwin (*Int. Crit. Tab.*, VII, 1931, p. 27) gives N_g = 1.4768 D, N_m = 1.4718 C, 1.4736 D, 1.4779 F, N_p = 1.4728 D, $N_g - N_p$ = 0.004 for $KClO_4$.

$CsClO_4$ is orthorhombic[22] with $a : b : c = 0.817 : 1 : 1.297$; crystals 001 tablets as in Fig. 220 or short prismatic with perfect 001 and 110 cleavages. G. = 3.327. The optic plane is 100; $Z = b$. (−) $2V = 62° 30'$. $N_g = 1.4786$ C, 1.4804 D, 1.4852 F, $N_m = 1.4770$ C, 1.4788 D, 1.4835 F, $N_p = 1.4734$ C, 1.4752 D, 1.4797 F, $N_g - N_p = 0.0052$ D. Colorless. Made by reaction of Cs_2SO_4 with $Ba(ClO_4)_2$.

NH_4ClO_4 is orthorhombic[22] with $a : b : c = 0.793 : 1 : 1.281$; crystals short prisms or 001 tablets with perfect 110 and distinct 001 cleavages. G. = 1.952. The optic plane is 001; $Z = b$. (+) $2V = 69° 34'$ C, 69° 54′ D, 70° 45′ F, $\rho > v$ distinct. $N_g = 1.4859$ C, 1.4881 D, 1.4931 F, $N_m = 1.4813$ C, 1.4833 D, 1.4881 F, $N_p = 1.4798$ C, 1.4818 D, 1.4865 F, $N_g - N_p = 0.0063$ D. Colorless. Made by reaction of $(NH_4)_2SO_4$ with $Ba(ClO_4)_2$.

$KClO_3$ is monoclinic with $a : b : c = 0.833 : 1 : 1.267$, $\beta = 80° 18'$. (Pseudotrigonal and closely related to calcite and soda niter.)[23] Crystals lamellar to equant basal tablets as in Fig. 221, with perfect 001 and 110 cleavages. Lamellar twinning on 001. G. = 2.32. Soluble in water. The optic plane is normal to 010; $X \wedge c$ [23] = + 48°. (−) $2V = 27°$, $\rho > v$ with distinct horizontal dispersion. $N_g = 1.5234$, $N_m = 1.5167$, $N_p = 1.4084$, $N_g - N_p = 0.115$ Na. Porter[24] gives: $X \wedge c = + 56° 10'$; (−) $2V = 26° 45'$, $N_g = 1.5241$, $N_m = 1.5174$, $N_p = 1.4099$, $N_g - N_p = 0.1142$. Colorless. Formed from H_2O solution.

$BaCl_2O_6 \cdot H_2O$ is monoclinic with $a : b : c = 1.142 : 1 : 1.198$, $\beta = 86° 26'$. Crystals columnar prismatic with perfect 011 and distinct 100 cleavages. G. = 2.99–(3.2). The optic plane is 010; $Z \wedge c = -23\frac{3}{4}°$. (+) $2V = 55\frac{1}{2}°$, $\rho < v$ weak. $N_g = 1.635$, $N_m = 1.577$, $N_p = 1.562$, $N_g - N_p = 0.073$. Colorless.

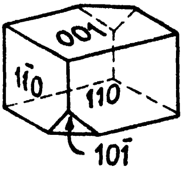

FIG. 221.—A crystal habit of $KClO_3$. (After Tutton.)

$H_2K_2TeI_2O_{10} \cdot 2H_2O$ is an iodate and tellurate of potassium; it is trigonal with $c = 1.933$. Crystals rhombohedral with 0001; common twinning on $10\bar{1}1$; no good cleavage. Uniaxial negative with $N_o = 2.142$, $N_e = 2.030$, $N_e - N_o = 0.112$ Na.

8. ANHYDROUS NITRATES

BaN_2O_6 is isometric and tetartohedral. Crystals double tetrahedrons, modified cubes, etc. Twinning on 111. G. = 3.25. F. = 1.

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[23] P. Fischer: *N. Jahrb. Min. Beil. Bd.* XXXII, 1911, p. 31.

[24] *Festsch. V. Goldschmidt*, 1928, p. 210.

Isotropic with N = 1.5665 C, 1.5711 D, 1.5825 F. Also weakly birefringent in sectors. Colorless. The natural substance, called *nitrobarite*, is very rare. BaN_2O_6 is miscible in all proportions [25] with PbN_2O_6.

SrN_2O_6 is isometric and tetartohedral in crystals like nitrobarite. G. = 2.99. Isotropic with N = 1.5667 Na;[26] 1.5878 Na.[27] Also weakly birefringent. No rotary polarization. Colorless. Formed from H_2O solution above 25° C.

PbN_2O_6 is isometric [28] and tetartohedral like nitrobarite; also monoclinic. The isometric crystals have G. = 4.54; isotropic with N = 1.773 C, 1.7815 D, 1.806 F. Also strong abnormal birefringence in sectors. Colorless. Formed from H_2O solution. Miscible in all proportions [25] with BaN_2O_6.

$LiNO_3$ is trigonal with a rhombohedral angle of 74° 20′. G. = 2.33; very hygroscopic. Uniaxial negative with [29] $N_o = 1.735$, $N_e = 1.435$, $N_o - N_e = 0.300$. Colorless. Formed from hot H_2O solution.

$NaNO_3$ is trigonal with $c = 0.828$, isomorphous with calcite. Perfect rhombohedral cleavage. H. = 1.5–2. G. = 2.27. F. = 1; deflagrates on heating. Deliquescent. Uniaxial negative with extreme birefringence; N_o = 1.5793 B, 1.5874 D, 1.5954 E, 1.6260 H, N_e = 1.3346 B, 1.3361 D, 1.3374 E, $N_o - N_e$ = 0.2513 D. (Schrauf); Merwin [30] gives: N_o = 1.5791 C, 1.5848 D, 1.5998 F, N_e = 1.3347 C, 1.3360 D, 1.3384 F, $N_o - N_e$ = 0.2488. N'_e on the cleavage = 1.467. Color white. Made from H_2O solution. The natural substance, called *soda niter* or *nitratite*, is very rare and found only in very arid regions.

$CsNO_3$ is hexagonal with $c = 1.236$. Crystals prismatic with pyramids. Distinct 0001 cleavage. G. = 3.69. Uniaxial positive with weak birefringence, decreasing to almost zero at the temperature of liquid air. $N_o = 1.55$,[31] $N_e = 1.56$, $N_e - N_o = 0.01$. Inverts at 161° C. to an isometric form. Formed from H_2O solution at 14° C.

KNO_3 (*saltpeter*) is orthorhombic with $a : b : c = 0.591 : 1 : 0.701$.

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[25] *Zeit. Kryst.*, LXVII, 1928, p. 148.

[26] *Zeit. Kryst.*, IV, 1880, p. 585.

[27] Behr: *N. Jahr. Min.*, 1903, I, p. 138. This value verified by E. T. Wherry: personal communication, Feb. 1928. Is SrN_2O_6 dimorphous?

[28] T. W. Richards and W. C. Schumb: *Jour. Am. Chem. Soc.*, XL, 1918.

[29] W. H. Fry: *U. S. Dept. Agric. Bull.* 1108, 1922, p. 11.

[30] *Int. Crit. Tab.*, VII, 1930, p. 26.

[31] Indices measured by Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) on "cæsium nitrate" of unknown formula.

Crystals equant or vertical acicular pseudohexagonal forms with perfect 011 and imperfect 010 and 110 cleavages. Twinning on 110. H. = 2. G. = 2.1. F. = 1. Deflagrates vividly on coal with violet flame color. The optic plane is 100; $X = c$. $(-)$ $2V = 6° 11'$ B, 7° 12′ D, 8° 5′ E, 10° 22′ H, $\rho < v$, strong. $N_g = 1.4994$ B, 1.5064 D, 1.5135 E, $N_m = 1.4988$ B, 1.5056 D, 1.5124 E, 1.5385 H, $N_p = 1.3328$ B, 1.3346 D, 1.3365 E, $N_g - N_p = 0.1718$ D. Merwin [2] gives: $N_g = 1.5002$ C, 1.5042 + D, 1.5144 F, $N_m = 1.4998$ C, 1.5038 D, 1.5139 F, $N_p = 1.3310$ C, 1.3320 D, 1.3347 F, $N_g - N_p = 0.1722$ D. Colorless. Becomes rhombohedral and uniaxial at 339° C. A third phase [32] is known. Saltpeter is made from H_2O solution. The natural substance, called *niter*, is found only in caves and desert regions.

KNO_3 and $RbNO_3$ form mix-crystals,[33] from 0 to at least 50 per cent $RbNO_3$ in which 2E decreases from 10° 51′ with $\rho < v$ in pure KNO_3 to 0° at about 32 per cent $RbNO_3$; with more $RbNO_3$ the optic angle opens in 010, attaining 2° 48′ with $\rho > v$ in crystals with 37 per cent $RbNO_3$. The density increases from 2.11 for pure KNO_3 to 2.35 for 50 per cent $RbNO_3$.

$RbNO_3$ is orthorhombic with $a : b : c = 1.737 : 1 : 0.711$; very nearly hexagonal. Crystals prismatic with imperfect 001 cleavage. G. = 3.12. Optic plane is 010; $Z = c$. $(+)$ $2V$ = very small,[34] $\rho > v$. $N_g = 1.524, N_m = 1.52, N_p = 1.51, N_g - N_p = 0.014$. Colorless. Formed from H_2O solution at 17° C.

NH_4NO_3 [35] is orthorhombic with $a : b : c = 0.909 : 1 : 1.055$; crystals pseudotetragonal long prisms or 010 tablets often twinned on 011, etc. Distinct 010 cleavage. G. = 1.725. The optic plane is 100; $X = b$; positive elongation. $(-)$ $2V = 35°$, $\rho < v$ weak. $N_g = 1.637$, $N_m = 1.605$ (668), 1.611 (588), 1.623 (502), $N_p = 1.413$, $N_g - N_p = 0.224$. Colorless. Made from solution at ordinary temperature. Stable between −16° C. and 32° C. This phase inverts on cooling at −16° C. to a tetragonal phase; on heating it inverts at 50° C. to another tetragonal phase, metastable at this temperature and stable from 84° C. to 125° C. The stable phase between 32° and 84° C. is orthorhombic or monoclinic; it has distinctly weaker birefringence than the phase stable at 20° C. and an optic angle of nearly 90°; the high temperature tetragonal phase is uniaxial and positive with still weaker birefringence (than the phase just described) though still very strong or extreme. The tetragonal phase inverts to an isometric phase at 125° C. which melts at 170° C. One high temperature phase has G. = 1.66 at 25° C.

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[32] F. C. Kracek: *Jour. Phys. Chem.*, XXXIV, p. 225.

[33] W. Stortenbeker: *Rec. Trav. Chim. P. B.*, XXXIII, 1914, p. 90. *Tables Ann. Const.* IV, p. 1067.

[34] Bolland (*Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275) gives sign as − with $N_g = 1.54$, $N_p = 1.535$.

[35] N. L. Bowen: *Jour. Phys. Chem.*, XXX, 1926, p. 721. H. E. Merwin: *Int. Crit. Tab.*, VII, 1930, p. 19

$TlNO_3$ is orthorhombic with $a : b : c = 0.511 : 1 : 0.651$. Crystals short prismatic, varied, with imperfect 010 cleavage. G. = 5.55. The optic plane is 010; X = c. (−) 2E = 111° 16′ red, 114° 59′ blue, $N_p = 1.817$, $N_g - N_p = ?$ Inverts at 80° to hexagonal and at 151° to isometric phase. Formed from H_2O solution at 20° ± C.

$AgNO_3$ is orthorhombic sphenoidal with $a : b : c = 0.943 : 1 : 1.37$. Crystals thick basal tablets, as in Fig. 222. Twinning on 001. G. = 4.35. F. = 209° C. Soluble in water. Optic plane is 100; Z = c. (+) 2V = 62°, $\rho < v$, strong (2E = 126° 37′ red, 133° 50′ blue). $N_g = 1.788$, $N_m = 1.744$, $N_p = 1.729$, $N_g - N_p = 0.059$. Colorless. Inverts at 159° C. with 0.25 per cent dilation to a hexagonal form? [36]

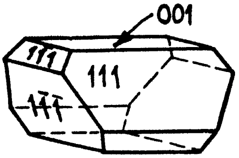

FIG. 222.—A crystal habit of $AgNO_3$. (After Groth.)

$K_2UO_2(NO_3)_4$[37] is monoclinic with $a : b : c = 0.639 : 1 : 0.619$, $\beta = 90° \pm$. Crystals 001 plates or prismatic. G. = 3.36. N_1 (vibration parallel to b) = 1.5422, N_2 (vibration in 010 at 26° 34′ from a toward c in the acute angle β = 1.5349. Color green.

9. HYDROUS NITRATES

$3Mg(NO_3)_2 \cdot 2Ce(NO_3)_3 \cdot 24H_2O$ [38] is trigonal; crystals rhombohedral. Uniaxial negative with N_o = 1.5204 C, 1.5249 D, 1.5346 F; N_e = 1.5135 C, 1.5176 D, 1.5267 F; $N_o - N_e$ = 0.0073 D, F − C for N_o = 0.0142.

$3Mg(NO_3)_2 \cdot 2Nd(NO_3)_3 \cdot 24H_2O$ [38] is trigonal; crystals rhombohedral. Uniaxial negative with N_o = 1.5228 C, 1.5266 D, 1.5368 F; N_e = 1.5156 C, 1.5192 D, 1.5286 F; $N_o - N_e$ = 0.0074 D, F − C for N_o = 0.0140.

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[36] *Comp. Rend.*, CXLIX, 1909, p. 569.

[37] E. L. Nichols and H. L. Howes: *Carn. Inst. Publ.* 298, 1919, p. 214. Rimbach (*Ber. Chem. Ges.*, XXXVII, 1904, p. 472) has described orthorhombic and trigonal forms of ammonium, and two orthorhombic forms of potassium, uranyl nitrate.

[38] E. E. Flint: *Zeit. Kryst. Ref.*, III, 1931, p. 94.

$3Mg(NO_3)_2 \cdot 2Pr(NO_3)_3 \cdot 24H_2O$ [38] is trigonal in rhombohedral crystals with $N_o = 1.5215$ C, 1.5255 D, 1.5356 F; $N_e = 1.5144$ C, 1.5182 D, 1.5277 F; $N_o - N_e = 0.0073$ D, F − C for $N_o = 0.0141$.

$3Mg(NO_3)_2 \cdot 2La(NO_3)_3 \cdot 24H_2O$ [38] is trigonal in rhombohedral crystals with $N_o = 1.5180$ C, 1.5220 D, 1.5319 F; $N_e = 1.5112$ C, 1.5150 D, 1.5242 F; $N_o - N_e = 0.0070$ D, F − C for $N_o = 0.0139$.

$UO_2N_2O_6 \cdot 6H_2O$ is orthorhombic with $a : b : c = 0.874 : 1 : 0.609$. 011 cleavage. G. = 2.76 − 2.81. Optic plane is 010; Z = c. (+) 2V = 44°, $\rho < v$ weak. $N_m = 1.497$ Na, $N_g - N_p$ = ? [39] Color siskin green with yellowish green fluorescence and X = clear yellow, Y = greenish yellow, Z = deep citron yellow.

$CaN_2O_6 \cdot 4H_2O$ is monoclinic with $a : b : c = 1.584 : 1 : 0.688$, $\beta = 81° 54'$. Crystals prismatic fibers with one perfect cleavage. Soft. G. = 1.9. F. = easy. Very hygroscopic. Acute bisectrix X normal to the cleavage.[40] (−) 2V = 5°, with slight dispersion, $N_g = 1.504$, $N_m = 1.498$, $N_p = 1.465$, $N_g - N_p = 0.039$. Colorless. Alters by dehydration to an isotropic chalky mass with N = 1.595, but returns to original condition in moist air. The natural substance, known as *nitrocalcite*, is very rare.

$(NH_4)_2UO_2(NO_3)_4 \cdot 2H_2O$ [37] is monoclinic with $a : b : c = 0.842 : 1 : 0.559$, $\beta = 85° 5'$. Crystals resemble cubes modified by pyramids; no cleavage. G. = 2.78. Dissociates at 140° C. Volatile. The optic plane and Z are normal to 010; $N_g = 1.639$, N_m = ?, $N'_p = 1.508$, $N_g - N'_p = 0.131$. Color sulphur yellow.

$CoN_2O_6 \cdot 6H_2O$ is monoclinic with $a : b : c = 1.172 : 1 : 1.925$, $\beta = 79° 0'$. Crystals 001 tablets with perfect 001 (or 100?) cleavage. The acute bisectrix makes an angle of about 18° with a normal to the cleavage. (−) 2E = 62½°. According to Bolland [41] "cobalt nitrate" (of unknown formula) is + with $N'_g = 1.52$, N_m = ?, $N'_p = 1.38$ (?), $N'_g - N'_p = 0.14$ (?). Color red. Formed from H_2O solution.

10. NITRITES

$SrN_2O_4 \cdot H_2O$ [42] is isometric of cubic habit with imperfect 111 cleavage and G. = 2.99. Isotropic with N = 1.589 Na. Colorless. Formed from cold H_2O solution.

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[39] Bolland (*Sitz. Akad. Wiss. Wien.*, CXIX, 1910, p. 275) gives for "uranium nitrate" of unknown formula: $N_g = 1.555$.

[40] E. S. Larsen: *U. S. Geol. Surv. Bull.*, 679, 1921, p. 116.

[41] *Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275.

[42] Not analyzed; perhaps more water.

$K_2PtI_2N_2O_4 \cdot 2H_2O$ is tetragonal with $c = 0.589$. Perfect 100 and distinct 001 cleavages. Uniaxial negative with $N_o = 1.7909$, $N_e = 1.6527$, $N_o - N_e = 0.1382$. Color reddish yellow with X = greenish yellow, Z = orange.

$K_2CdN_4O_8$ is orthorhombic with $a : b : c = 0.537 : 1 : 1.924$; pseudohexagonal. Crystals columnar prismatic or 010 tablets with distinct 110 cleavages. The optic plane is 100; $Z = c$. (+) $2V = 48°$. $N_g = 1.608$ Na, $N_m = 1.565$, $N_p = 1.556$ (calc.), $N_g - N_p = 0.052$. Color pale yellow.

$Na_2RuN_5O_{10} \cdot 2H_2O$ is monoclinic with $a : b : c = 1.509 : 1 : 1.022$, $\beta = 86° 13'$. Crystals prismatic; twinning on 100 of the Carlsbad type; no good cleavage. The optic plane is 010; $Z \wedge c = 84° 18'$ Na, (84° 34′ Tl). (+) $2V = 24° 50'$ Li, 25° 14′ Na, 25° 37′ Tl. $N_g = 1.7163$ Na, $N_m = 1.5847$ Li, 1.5943 Na, 1.6041 Tl, $N_p = 1.5889$ Na, $N_g - N_p = 0.1274$ Na. Color orange with X = yellow, Z = orange.

$K_2PtBr_2N_2O_4 \cdot H_2O$ is triclinic with $a : b : c = 0.992 : 1 : 1.317$, $\alpha = 90° 58'$, $\beta = 91° 43'$, $\gamma = 91° 7'$. Crystals 001 (or $20\bar{1}$) tablets or complex. Very common twinning on 001. One optic axis is nearly normal to 001; the other, visible through $20\bar{1}$, makes an angle of 30° 5′ with a normal to this face. $X \wedge$ normal to 001 = 47° 55′; $X \wedge$ normal to $20\bar{1}$ = 63° 10′; $Z \wedge$ normal to 001 = 42° 7′; $Z \wedge$ normal to $20\bar{1}$ = 32° 27′. (+) $2V = 72° 21'$. Axis A, visible through 001, is very little dispersed with $\rho > v$; axis B, visible through $20\bar{1}$ shows strong inclined dispersion with $\rho < v$. $N_g = 1.757$ D, $N_m = 1.6684$, $N_p = 1.626$, $N_g - N_p = 0.131$ Na. Color yellow.

VII BORATES

"Aluminates" and "ferrites," which are related chemically to borates, have been included among the oxides. All the acids of boron are considered together and classified on the basis of the valence of the metals present. Rhenates are also included.

1. BORATES OF MONOVALENT BASES

$Na_2B_4O_7 \cdot 5H_2O$ is rhombohedral[1] with $c = 1.87$. Crystals pseudo-octahedral with 0001 and $10\bar{1}1$; also $01\bar{1}2$. No cleavage. G. = 1.88. Uniaxial positive with $N_o = 1.461$, $N_e = 1.474$, $N_e - N_o = 0.013$. White to colorless with vitreous luster. Made by boiling a solution of borax. The natural substance is known as *tincalconite*.

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[1] W. T. Schaller: *U. S. Geol. Surv. Prof. Pap.*, 158, 1930, p. 137.

$NH_4B_5O_8 \cdot 4H_2O$ is orthorhombic with $a : b : c = 0.983 : 1 : 0.820$. Crystals pyramidal, often twinned on 101, with distinct 010 cleavage. Optic plane is 010; $Z = b$. (+) $2E = 46° 30'$ red, $48° 24'$ blue. $N'_g = 1.485$,[2] $N_m = ?$, $N'_p = 1.44$, $N'_g - N'_p = 0.045$. Colorless.

$Na_2B_4O_7 \cdot 10H_2O$ is monoclinic[3] with $a : b : c = 1.0995 : 1 : 0.5632$, $\beta = 72° 25'$. Crystals prismatic, resembling pyroxene, as in Fig. 223 with twinning on 100, and perfect 100 and distinct 110 cleavages. H. = 2. G. = 1.70. The optic plane is normal to 010; $Z \wedge c = -56°$ (red), $-55° 50'$ Na, $-54° 39'$ (green). (−) $2V = 39° 28'$ (red), $39° 10'$ Na, $38° 35'$ (green), $N_g = 1.4699$ C, 1.4724 D, 1.4778 F, $N_m = 1.4669$ C, 1.4694 D, 1.4750 F, $N_p = 1.4445$ C, 1.4467 D, 1.4517 F, $N_g - N_p = 0.0257$ D. Colorless. Made from H_2O solution of boric acid and sodium carbonate at ordinary temperature. The natural substance, called *borax*, is an abundant deposit of rare salt lakes. Borax glass ($Na_2B_4O_7$) is isotropic with $N = 1.5147$ Na. Colorless.

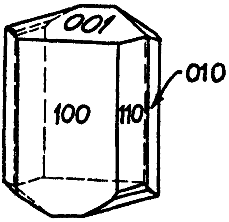

FIG. 223.—A crystal habit of borax, $Na_2B_4O_7 \cdot 10H_2O$.

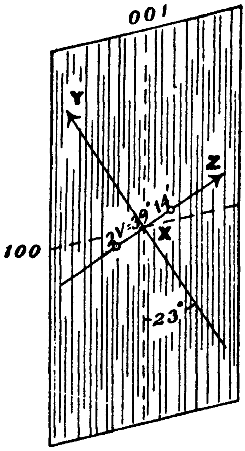

FIG. 224.—Optic orientation of borax, $Na_2B_4O_7 \cdot 10H_2O$.

$Na_2B_4O_7 \cdot 4H_2O$ is monoclinic[1] with $a : b : c = 1.523 : 1 : 1.699$, $\beta = 71° 8'$. Crystals nearly equant to elongated parallel with c, with perfect 001 and 100 and fair $\bar{1}01$ cleavages; cleavage fragments are elongated parallel with b. H. = 2.5. G. = 1.91. Fuses easily to clear glass. Slowly soluble in H_2O. The optic plane and Z are normal to 010; $X \wedge c = +70\frac{1}{2}°$. (−) $2V = 80°$, $\rho > v$ distinct. $N_g = 1.487$, $N_m = 1.472$, $N_p = 1.455$, $N_g - N_p = 0.032$. Colorless to white. The natural substance is called *kernite*. Made by heating borax in a closed tube to about 150° C. for several days, cooling, wetting, and reheating to about 150° C.

[2] Indices measured by Bolland (*loc. cit.*) on "ammonium borate" of unknown formula.

[3] G. Tschermak: *Sitz. Akad. Wiss. Wien*, LVII, 2, 1868, p. 641.

2. BORATES OF DIVALENT BASES

CaB_2O_4 is orthorhombic with $a : b : c = 0.539 : 1 : 0.372$. Crystals 100 plates elongated parallel to c with perfect 100, distinct 101 and poor 010 cleavages. G. = 2.65. The optic plane is 001; $X = a$. $(-)$ $2E = 90° 24'$ Na; $2V = 51°$. $N_g = 1.682$, $N_m = 1.656$, $N_p = 1.540$, $N_g - N_p = 0.142$. Color white. Formed from fusion.

$Mg_3B_2O_6$ is orthorhombic with $a : b : c = 0.641 : 1 : 0.549$. Crystals prismatic with good 110 cleavages. G. = 2.99. The optic plane is 010; $Z = c$. $(+)$ $2E = 43° 18'$, $\rho > v$ weak; $2V = 25°$. $N_g = 1.6748$, $N_m = 1.6537$, $N_p = 1.6527$, $N_g - N_p = 0.0221$ Na. Color white. Formed from fusion.

$Mn_3B_4O_9$ is triclinic[4] with $a : b : c = 1.837 : 1 : 2.012$, $\alpha = 92° 6'$, $\beta = 123° 58'$, $\gamma = 76° 26'$. Crystals prismatic with perfect 001 and distinct 010 cleavages. G. = 3.61. An optic axis is inclined 90° to a normal to 001; X makes an angle of 63° with a normal to 110, 27° 43′ with a normal to 001 and 29° 11′ with a normal to 100. $(-)$ $2V = 55° 47'$. $N_g = 1.776$, $N_m = 1.738$, $N_p = 1.617$, $N_g - N_p = 0.159$. Formed from fusion.

3. BORATES OF TRIVALENT BASES

Al_3BO_6 is orthorhombic with $a : b : c = 0.974 : 1 : 0.679$. Crystals acicular. The optic plane is 010; $Z = c$. $(+)$ $2V = 87°$. $N_g = 1.623$, $N_m = 1.603$, $N_p = 1.586$, $N_g - N_p = 0.037$. Colorless. Formed from fusion.

4. BORATES OF DIVALENT AND MONOVALENT BASES

$NaCaB_5O_9 \cdot 5H_2O$ is monoclinic[1] with $a : b : c = 1.105 : 1 : 0.524$, $\beta = 72° 16'$. Crystals long prismatic, radiating, with perfect 110 cleavage. No twinning observed. H. = 2.5, G. = 2.14. Fuses easily with swelling. The optic plane is 010, $Z \wedge c = -12°$. $(+)$ $2V = 73°$, $\rho > v$. $N_g = 1.544$, $N_m = 1.525$, $N_p = 1.515$, $N_g - N_p = 0.029$. Colorless or white. The natural substance has been named ***kramerite***. Formed by heating a mixture of two parts of ulexite and one of borax to about 60° C.

5. RHENATES

$KReO_4$ is tetragonal[5] with $c = 1.582$. Crystals pyramidal. Uniaxal positive with $N_o = 1.643$, $N_e = 1.673$, $N_e - N_o = 0.030$.

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[4] The formula is $Mn_2B_2O_5$ according to Le Chatelier: *Comp. Rend.*, CXIII, 1891.

[5] *Zeit. Kryst.*, LXII, 1930, p. 541.

VIII. SULPHATES, ETC.

Sulphates, selenates, tellurates, chromates, molybdates, tungstates and uranates are included in this division, which begins with sulphites. The arrangement of salts of the normal acids begins with anhydrous normal salts of monovalent bases and maximum symmetry and ends with hydrous basic salts of several bases and of minimum symmetry. This is followed by the polythionates and polychromates; as an appendix are added salts of two or more oxygen acids (including one acid of this division).

1. SULPHITES, SELENITES, ETC.

Na_2SO_3 is hexagonal [1] in prisms and tablets. Uniaxial negative with $N_o = 1.565 \pm$, $N_e = 1.515 \pm$, $N_o - N_e = 0.050 \pm$. Colorless.

$NaHSO_3$ occurs in formless grains [1a] with (+) $2V = 65° \pm$, $N_g = 1.685 \pm$, $N_m = 1.526$, $N_p = 1.474$, $N_g - N_p = 0.211 \pm$. Colorless.

$CaSO_3 \cdot 2H_2O$ occurs in rectangular grains [1] with varied elongation and parallel extinction. (+) $2V = 30° \pm$, $N_g = 1.628–1.635$, $N_m = 1.595–1.605$, $N_p = 1.590–1.600$, $N_g - N_p = 0.038–0.035$. Colorless.

2. ANHYDROUS SULPHATES, ETC., OF MONOVALENT BASES

$NaK_3(CrO_4)_2$ is trigonal with $c = 1.286$; crystals basal tablets or rhombohedral with distinct basal cleavage. Single crystals form only from warm solutions. G. = 2.767. Uniaxial positive with $N_o = 1.7278$ Na, $N_e = 1.7361$, $N_e - N_o = 0.0083$. Strong dispersion, giving an unusual interference figure. Also monoclinic, pseudohexagonal, biaxial positive, 2V small; Z nearly normal to 001; Y = *b*. Color in plates 1 mm. thick, X = orange yellow, Z = lemon yellow.

$LiKSO_4$ is hexagonal with $c = 1.676$. Crystals columnar prismatic, basal tablets, or plainly hemimorphic. Twinning often obscures the hemimorphism. Imperfect basal cleavage. H. = 3. G. = 2.39. Uniaxial negative [1b] with $N_o = 1.4703$ C, 1.4723 D, 1.4765 F, $N_e = 1.4697$ C, 1.4717 D, 1.4759 F, $N_e - N_o = 0.0006$ D. Rotates the plane of polarization. Colorless. Formed from acid solution. Inverts at about 435° C.

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[1] Salt prepared by F. R. Bichowsky; properties determined by H. E. Merwin—personal communication, Mar. 25, 1931.

[1a] Properties determined by H. E. Merwin—personal communication, Mar. 25, 1931.

[1b] *Zeit. Kryst.*, LXXI, 1929, p. 141.

$(NH_4)_2SO_4$ is orthorhombic with $a : b : c = 0.563 : 1 : 0.732$ and distinct 001 cleavage. Crystals 010 tablets, nearly equant or short brachydomatic. Pseudohexagonal twinning on 110. H. = 2. G. = 1.77. F. = 1. Volatile. The optic plane is 010; $Z = a$. (+) $2V = 52° 17'$ C, 52° 12′ D, 52° 0′ F, $\rho > v$ very weak. $N_g = 1.5302$ C, 1.5330 D, 1.5394 F, $N_m = 1.5204$ C, 1.5230 D, 1.5291 F, $N_p = 1.5182$ C, 1.5209 D, 1.5270 F, $N_g - N_p = 0.0121$ Na. Colorless or yellow. Made from H_2O solution. The natural substance, known as *mascagnite,* occurs about volcanoes, in guano, and as a product of combustion of coal; rare.

Na_2SO_4 is orthorhombic [2] with $a : b : c = 0.598 : 1 : 1.252$. Crystals pyramidal, as in Fig. 225, short prismatic or basal plates with distinct 001 cleavage. H. = 2.7. G. = 2.664. F. = 1.5 – 2. The optic plane is 001; $Z = a$. (+) $2V = 83° 38'$ Li, 83° 35′ Na, 83° 32′ Tl, $\rho > v$ weak. $N_g = 1.484$, $N_m = 1.477$, $N_p = 1.471$, $N_g - N_p = 0.013$. Colorless. Made from H_2O solution at about 50° C. The natural substance, called *thenardite,* is a rare salt lake deposit and also found about volcanoes.

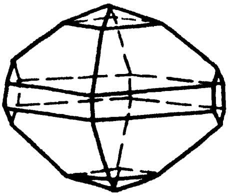

FIG. 225.—A crystal habit of Na_2SO_4. (After Groth.)

Na_2SO_4 inverts [3] at about 160°–180° C. to a phase (called Na_2SO_4 IV) which is probably monoclinic with birefringence stronger than that of thenardite and $N_g = 1.480$, $N_m = ?$, $N_p < 1.46$, $N_g - N_p > 0.02$. Na_2SO_4 inverts again at about 185° C. to an orthorhombic phase (called Na_2SO_4 III) supposed to be isomorphous with K_2SO_4; G. = 2.696; very stable when cooled to ordinary temperature; birefringence much less than that of thenardite with all indices between 1.480 and 1.485; optically negative. Na_2SO_4 inverts finally at 241° C. to a hexagonal phase (called Na_2SO_4 I) probably isomorphous with the high temperature phase of K_2SO_4; it is negative uniaxial with indices lower than 1.475 and very weak birefringence; it was called *metathenardite* by Lacroix, who found it at Mont Pelée. These inversions occur very slowly, so that several phases may be found together after heating and cooling. On cooling, if the change at 241° C. be prevented, an inversion occurs reversibly at 236° C. to a phase (called Na_2SO_4 II) with very strong birefringence, having $N_g = 1.480$, $N_m = ?$, N_p much less than 1.465; not stable at low pressure.

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[2] H. S. Washington and H. E. Merwin: *Am. Mineral.*, VI, 1921, p. 121.

[3] F. C. Kracek: *Jour. Phys. Chem.*, XXXIII, 1929, p. 1281; XXXIV, 1930, p. 188.

K_2SO_4 is orthorhombic[4] with $a : b : c = 0.5727 : 1 : 0.7418$ and distinct 010 and 001 cleavage. Crystals nearly equant or 010 tablets or short brachydomatic, as in Fig. 226. Pseudohexagonal by twinning on 110. G. = 2.66. Soluble in water. The optic plane is 100; Z = c. (+) 2V = 67° 24′ C, 67° 20′ D, 67° 7′ F, $\rho > v$ weak. N_g = 1.4954 C, 1.4973 D, 1.5023 F, N_m = 1.4928 C, 1.4947 D, 1.4995 F, N_p = 1.4916 C, 1.4935 D, 1.4982 F, $N_g - N_p$ = 0.0038 D. Colorless. Inverts to uniaxial negative phase at about 650° C. Very rare in nature, where it is known as *arcanite*. Apparently miscible in all proportions with K_2CrO_4, *q. v.*

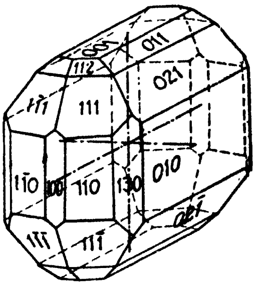

FIG. 226.—A combination of crystal forms in K_2SO_4.

Rb_2SO_4 is orthorhombic[4] with $a : b : c = 0.572 : 1 : 0.749$; crystals varied, nearly equant or 100 tablets; may be pseudohexagonal twins on 110. Distinct 010 and imperfect 001 cleavage. G. = 3.61. The optic plane is 001 below 50° C.; above 50° C. it is 010; acute bisectrix is a to 180° C., above that it is c and negative. (+) 2V = 29° 5′ C, 33° 0′ D, 41° 35′ F. Uniaxial at 36° for Li, at 38° for Na, at 44° for Tl. N_g = 1.5124 C, 1.5144 Na, 1.5194 F, N_m = 1.5113 C, 1.5133 D, 1.5183 F, N_p = 1.5112 C, 1.5131 D, 1.5181 F, $N_g - N_p$ = 0.0013 D. Formed from H_2O solution.

Cs_2SO_4 is orthorhombic[4] with $a : b : c = 0.571 : 1 : 0.753$; crystals tabular parallel to 001 or 010 with all three pinacoids prominent. Distinct 010 and imperfect 001 cleavage. G. = 4.24. The optic plane is 010; X = c. (−) 2V = 65° 8′ C, 65° 20′ D, 65° 39′ F, $\rho < v$ weak. N_g = 1.5637 C, 1.5662 D, 1.5725 F, N_m = 1.5619 C, 1.5644 D, 1.5706 F, N_p = 1.5573 C, 1.5598 D, 1.5660 F, $N_g - N_p$ = 0.0064 D. Formed from H_2O solution.

Tl_2SO_4 is orthorhombic[4] with $a : b : c = 0.555 : 1 : 0.733$; crystals tabular parallel to 010 usually elongated parallel to a; perfect 010 and nearly perfect 001 cleavage. G. = 6.765. The optic plane is 010; Z = a. (+) 2V = 68° 8′ C, 68° 4′ D, $\rho > v$ very weak. N_g = 1.8753 C, 1.8853 D, 1.9126 F, N_m = 1.8579 C, 1.8671 D, 1.8935 F, N_p = 1.8509 C, 1.8600 D, 1.8859 F, $N_g - N_p$ = 0.0253 D. Formed from dilute H_2SO_4 solution.

K_2CrO_4 is orthorhombic with $a : b : c = 0.569 : 1 : 0.730$; crystals varied; twinning pseudohexagonal; fair 010 and 001 cleavages.

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[4] A. E. H. Tutton: *Trans. Chem. Soc.*, LXV, 1895, p. 628.

G. = 2.74. Optic plane is 100; X = *b*. According to Mallard:[5] (−) 2V = 29° 25′, $\rho > v$ weak. N_g = 1.7305 C, N_m = 1.7131 C, 1.7254 Na, 1.7703 F, N_p = 1.6873, $N_g - N_p$ = 0.0432. According to Corio:[6] (−) 2V = 57° 47′ Na, N_g = 1.7304, N_m = 1.7261, N_p = 1.7087, $N_g - N_p$ = 0.0217. Miscible in all proportions with K_2SO_4. With 19 per cent K_2SO_4, N_g = 1.6727, N_m = 1.6688, N_p = ? With 79.4 per cent K_2SO_4, N_g = 1.5432, N_m = 1.5378, N_p = 1.5316, $N_g - N_p$ = 0.0115. Pure K_2CrO_4 is bright yellow. It has a reversible inversion at 666° C. The natural substance, known as *tarapacaite*, is found in calcite in Chile and Peru. Very rare.

K_2SeO_4 is orthorhombic with $a : b : c$ = 0.573 : 1 : 0.732; crystals tabular parallel to 010 or acicular, prismatic, vertically striated, often twinned as trillings. Perfect 010 and distinct 001 cleavage. G. = 3.067. Deliquescent. The optic plane is 100; Z = *c*. (+) 2V = 76° 47′ C, 76° 53′ D, 76° 57′ F, $\rho < v$ distinct. N_g = 1.5418 C, 1.5446 D, 1.5518 F, N_m = 1.5362 C, 1.5390 D, 1.5460 F, N_p = 1.5325 C, 1.5352 D, 1.5421 F, $N_g - N_p$ = 0.0094 D. Formed from H_2O solution.

Rb_2SeO_4 is orthorhombic with $a : b : c$ = 0.571 : 1 : 0.739; crystals brachydomatic columnar. Perfect 010 and distinct 001 cleavage. G. = 3.902. Deliquescent. The optic plane is 100; Z = *c*. (+) 2V = 68° 55′ C, 68° 53′ D, 68° 49′ F, $\rho > v$ very weak, N_g = 1.5554 C, 1.5582 D, 1.5655 F, N_m = 1.5509 C, 1.5537 D, 1.5609 F, N_p = 1.5487 C, 1.5515 D, 1.5586 F, $N_g - N_p$ = 0.0067 D. Formed from H_2O solution.

Cs_2SeO_4 is orthorhombic with $a : b : c$ = 0.570 : 1 : 0.742; crystals thick basal tablets. Perfect 010 and distinct 001 cleavage. G. = 4.456. Very deliquescent. The optic plane is 001; X = *b*. (−) 2V = 73° 7′ C, 71° 49′ Na, 68° 58′ F, $\rho > v$ distinct. N_g = 1.5969 C, 1.6003 D, 1.6084 F, N_m = 1.5965 C, 1.5999 D, 1.6080 F, N_p = 1.5955 C, 1.5989 D, 1.6070 F, $N_g - N_p$ = 0.0016 D. The optic angle increases rapidly with heat, the mineral becoming positive at about 60° C., and uniaxial at about 95° C.; at 150° it is again decidedly biaxial (positive) with the optic plane 010; at 280° C. the optic angle about Z (= *b*) is much more than 90° and the substance is again negative (X = *c*). Formed from H_2O solution.

Tl_2SeO_4 is orthorhombic with $a : b : c$ = 0.555 : 1 : 0.724. Crystals columnar brachydomatic or tabular parallel to 010, 001 or 011. 010

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[5] *Bull. Soc. Fr. Min.*, III, 1880, p. 3; N_m as measured by Topsøe and Christiansen.

[6] *Zeit. Kryst.*, XXXII, 1900, p. 524.

and 001 cleavages. G. = 6.875. The optic plane is 001; X = *b*. (−) 2V = 72° 58′ Na, $\rho > v$ weak. N_g = 1.9500 C, 1.9640 D, 1.9987 F, N_m = 1.9450 C, 1.9592 D, 1.9942 F, N_p = 1.9355 C, 1.9493 D, 1.9840 F, $N_g - N_p$ = 0.0147 D. Formed from dilute H_2SO_4 solution.

NH_4LiSO_4 is orthorhombic with $a : b : c$ = 1.680 : 1 : 0.979. Crystals 100 plates with horizontal striations on 010 and horizontal and vertical striations on prism faces; perfect 100 cleavage. G. = 1.20. The optic plane is 010; Z = *b*. (+) 2V = 36° 32′ red, 49° 4′ green, N_m = 1.437 Li, $N_g - N_p$ = ? Colorless. Made from cold H_2O solution. A pseudohexagonal phase is also known with $a : b : c$ = 1.73 : 1 : 1.67; crystals 010 tablets or columnar parallel to *c* or *b*; G. = 1.16. Common twinning on 110; perfect 001 cleavage. The optic plane is 010; Z = *c*. (+) 2E = 63° 30′ red, 61° 32′ green. Made from hot H_2O solution.

Rb_2CrO_4 is orthorhombic with $a : b : c$ = 0.566 : 1 : 0.749. Crystals elongated parallel to *a*, with 001 cleavage. The optic plane is 010; X = *c*. (−) 2H = 74°, $\rho < v$. Bolland[7] gives for "rubidium chromate" (hydrated?): N_1 = 1.72, N_2 = 1.71; these are probably N_g and N_m. Made from H_2O solution.

NH_4HSO_4 is orthorhombic with $a : b : c$ = 0.613 : 1 : 0.744. Crystals long prismatic or thick 010 tablets with perfect 100 cleavage. G. = 1.82. The optic plane is 010 and Z = *c*. (+) 2V[7a] = 60° ± with weak dispersion; N_g = 1.510, N_m = 1.473, N_p = 1.463, $N_g - N_p$ = 0.047. Colorless.

$RbHSO_4$ is orthorhombic with $a : b : c$ = 0.75 : 1 : 0.60. The optic plane is 010; X = *c*. (+) 2V = 55° 52′, $\rho < v$ weak. N_m = 1.473, $N_g - N_p$ = ?

$(NH_4)_2SeO_4$ is orthorhombic in isomorphous mixtures (and alone?); the pure salt is said to have $a : b : c$ = 0.534 : 1 : 0.75 and G. = 2.077. Crystals 010 tablets. The optic plane is 010; X = *c*. (−) 2V = 55° 36′ red, 58° 54′ blue. N_m = 1.56. The salt is commonly monoclinic with $a : b : c$ = 1.890 : 1 : 1.199, β = 64° 31′. Crystals tabular parallel to 100 or 001 or columnar parallel to *b* with 100 and 001 well developed; twinning on 001 common. Perfect 100 and 001 and distinct 010 cleavages. G. = 2.194. The optic plane is normal to 010 and nearly parallel to 001; $Z \wedge c$ = +113° 11′. (+) 2V = 37° 19′ C,

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[7] *Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275.

[7a] Indices and optic angle measured by H. E. Merwin—personal communication, Mar. 25, 1931.

37° 54′ D, 38° 44′ F, $\rho < v$ weak. N_g = 1.5806 C, 1.5846 D, 1.5935 F, N_m = 1.5594 C, 1.5630 D, 1.5713 F, N_p = 1.5571 C, 1.5607 D, 1.5687 F, $N_g - N_p$ = 0.0239 D. Becomes uniaxial at 114° C. for D and at 119° C. for F. Made from H_2O solution.

Li_2SO_4 is monoclinic with $a : b : c$ = 1.004 : 1 : 1.380, β = 87° 52′. Crystals pseudooctahedral and pyramidal with perfect 101, $10\bar{1}$ and 011 cleavages. G. = 2.23. Unstable in air. The optic plane is normal to 010; $X \wedge c = -31°$. (−) 2V = 72° 58′, $\rho > v$ weak. N_m = 1.465, $N_g - N_p$ = rather weak. Colorless. Made from fusion.

$H(NH_4)_3(SO_4)_2$ is monoclinic[8] with $a : b : c$ = 1.739 : 1 : 3.881, β = 89° 13′. Twinning on 110 or 310 frequent. Distinct 001 cleavage. G. = 1.83. The optic plane is normal to 010; $X \wedge c$ = 17½°. (−) 2V = 52°, N_g = 1.5230 Li, 1.5276 Na, 1.5355 Tl, N_m = 1.4964 Li, 1.5021 Na, 1.5091 Tl, N_p = 1.4914 Li, 1.4959 Na, 1.5040 Tl, $N_g - N_p$ = 0.0317 Na. Inverts to a uniaxial phase. Colorless. Made by cooling a solution of $(NH_4)_2SO_4$ and H_2SO_4.

$HK_3(SO_4)_2$ is monoclinic with $a : b : c$ = 1.722 : 1 : 3.767, β = 89° 49′; crystals tabular or pyramidal; twinned on 110, or on 310 in pseudohexagonal trillings. Distinct 001 cleavage. G. = 2.59. The optic plane[8] is normal to 010; $X \wedge c = -35°$. (−) 2V = 60°, N_g = 1.5259 Na, N_m = 1.4899, N_p = 1.4793, $N_g - N_p$ = 0.0466. Colorless. Formed from H_2O solution of $HKSO_4$ from which K_2SO_4 has first separated.

3. HYDROUS SULPHATES, ETC., OF MONOVALENT BASES

$Na_2WO_4 \cdot 2H_2O$ is orthorhombic with $a : b : c$ = 0.800 : 1 : 0.647. Crystals 001 tablets with good 001 cleavage. G. = 3.25. The optic plane[1a] is 100; X = *b*. (+) 2V = 25° D, $2V_F - 2V_C$ = 9°; N_g = 1.5695 ±, N_m = 1.5533 ±, N_p = 1.5526 ±, $N_g - N_p$ = 0.0169 ±. Dispersion (F–C) for N_g = 0.0138, for N_m = 0.0130, for N_p = 0.0123.

$Na_2SO_4 \cdot 10H_2O$ is monoclinic with $a : b : c$ = 1.116 : 1 : 1.237, β = 72° 15′. Crystals columnar parallel to *b*, as in Fig. 227, 001 tablets elongated parallel to *b*, or short prismatic with perfect 100 cleavage. Twinning on 100. H. = 1.5–2. G. = 1.46. F. = 1.5. Effloresces rapidly. The optic plane is normal to 010; $Z \wedge c$ = +31° Li, 26.5° blue. (−) 2E = 122° 48′ Li, $\rho > v$ weak with strong crossed dispersion; 2V = 76°. N_g = 1.398, N_m = 1.396, N_p = 1.394, $N_g - N_p$ = 0.004 (Larsen). Sections normal to X give abnormal interference colors without extinction; other sections give sharp extinction. Colorless. Made from H_2O solution. The natural substance, called *mirabilite*, is a rare salt lake deposit and also found about volcanoes.

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[8] P. Fischer: *N. Jahrb. Min. Bl. Bd.* XXXII, 1911, p. 31.

$Na_2CrO_4 \cdot 4H_2O$ is monoclinic in crystals elongated parallel to a with $a : b : c = 1.112 : 1 : 1.062$, $\beta = 74° 56'$. No distinct cleavage. Twinning on 001. Deliquescent. The optic plane is 010 for light of wave-length less than 645 mμ and normal to 010 for light of wave-length more than 645 mμ, being uniaxial positive for $\lambda = 645$ mμ. (+) $2V = 31° - 12°$ for $\lambda = 450 - 600$ mμ; $N_g = 1.536$, $N_m = 1.285$, $N_p = 1.221$ for 670 mμ; $N_g = 1.545$, $N_m = 1.297$, $N_p = 1.291$ for 650 mμ; $N_g = 1.551$, $N_m = 1.383$, $N_p = 1.308$ for 625 mμ; $N_g = 1.561$, $N_m = 1.447$, $N_p = 1.321$, $N_g - N_p = 0.240$ for 589 mμ; $N_g = 1.576$, $N_m = 1.471$, $N_p = 1.342$ for 535 mμ. $Z \wedge c = 2\frac{1}{2}°$ for 650 mμ, $5\frac{1}{2}°$ for 573 mμ, 17° for 472 mμ. Remarkably strong inclined dispersion for $\lambda < 645$ mμ. Made from solution at 25°–29° C.

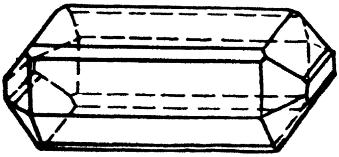

FIG. 227.—A crystal habit of $Na_2SO_4 \cdot 10H_2O$.

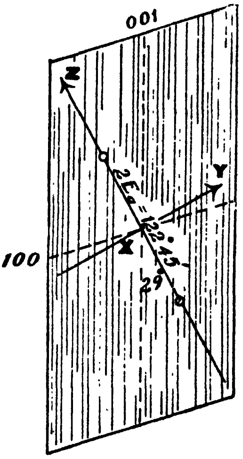

FIG. 228.—Optic orientation of $Na_2SO_4 \cdot 10H_2O$.

$Li_2SO_4 \cdot H_2O$ is monoclinic[9] with $a : b : c = 1.607 : 1 : 0.563$, $\beta = 87° 55'$. Crystals $\bar{1}01$ plates elongated parallel to b. Twinning on $\bar{1}01$ common. Perfect 101, distinct 100 and indistinct 110 cleavages. G. = 2.06. The optic plane is normal to 010; $X \wedge c = -36° 32'$. (−) $2V = 78° 24'$, $\rho < v$ very weak. $N_g = 1.488$, $N_m = 1.477$, $N_p = 1.459$, $N_g - N_p = 0.029$. Colorless. Made from acid solution.

$NaHSO_4 \cdot H_2O$ is monoclinic with $a : b : c = 0.997 : 1 : 1.048$, $\beta = 60° 25'$. Crystals prismatic, often platy parallel 110 or $1\bar{1}0$. Bolland[10] measured on "sodium bisulphate" (hydrated?): $N_g = 1.47$,

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[9] A. Johnsen: *N. Jahrb. Min. Beil. Bd.* XXXIX, 1914, p. 500. Scacchi in Dufet (*Rec. Don. Num.*, III, 1900, p. 1238) gives $N_m = 1.510$ D.

[10] *Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275.

$N_m = 1.46$, $N_p = 1.43$, $N_g - N_p = 0.04$. Colorless. Made from a solution of Na_2SO_4 containing an excess of H_2SO_4.

4. ANHYDROUS SULPHATES, ETC., OF DIVALENT BASES

$CaWO_4$ is tetragonal with $c = 1.530$; crystals pyramidal or tabular with distinct 111 cleavage. H. = 4.5-5. G. = 6.12. F. = 5. Decomposed by HCl leaving a yellow residue. Uniaxial positive[11] with $N_o = 1.9124$ C, 1.9200 D, 1.9298 E, 1.9344 (475), $N_e = 1.9281$ C, 1.9365 D, 1.9468 E, $N_e - N_o = 0.0165$ D. Color white. Made by adding a solution of sodium tungstate to a hot acid solution of calcium chloride; also by fusion. The natural substance, called *scheelite*, often contains some molybdic acid radical.

$CaWO_4$ with 10.3 per cent $Ce_2(WO_4)_3$ is tetragonal[11] with $c = 1.532$. Uniaxial positive with $N_o = 1.9197$ C, 1.9266 D, 1.9365 E, $N_e = 1.9331$ C, 1.9412 D, 1.9517 E, $N_e - N_o = 0.0146$ D. Color yellow. Made from fusion at 1100° C.

$CaMoO_4$ is tetragonal[11] with $c = 1.551$; crystals pyramidal with distinct 111 cleavage. H. = 3.5. G. = 4.35. F. = 4. Decomposed by HCl. Uniaxial positive with $N_o = 1.959$, $N_e = 1.967$ for 667 mμ; $N_o = 1.974$, $N_e = 1.984$, $N_e - N_o = 0.010$ for 570 mμ; $N_o = 1.982$, $N_e = 1.993$ for 553 mμ. Made by fusion of calcium chloride with sodium molybdate. The natural substance, called *powellite*, commonly contains some tungstic acid radical.

$CaMoO_4$ with 39 per cent $Di_2(MoO_4)_3$ is tetragonal[11] with $c = 1.542$. Uniaxial positive[12] with $N_o = 2.006$, $N_e = 2.001$, $N_o - N_e = 0.005$. Color violet. Made from fusion.

$CaMoO_4$ with 4.7 per cent $Y_2(MoO_4)_3$ is uniaxial positive[11] with $N_o = 1.978$, $N_e = 1.986$, $N_e - N_o = 0.008$ for 667 mμ; $N_o = 1.993$, $N_e = 2.002$, $N_e - N_o = 0.009$ for 570 mμ; $N_o = 2.003$, $N_e = 2.012$, $N_e - N_o = 0.009$ for 533 mμ. Color white.

$CaMoO_4$ with 21 per cent $Ce_2(MoO_4)_3$ and 24.7 per cent $Y_2(MoO_4)_3$ is tetragonal[11] with $c = 1.544$. Crystals pyramidal. Uniaxial positive with $N_o = 1.9905$ C, 2.0004 D, 2.0163 E, $N_e = 1.9939$ C, 2.0049 D, 2.0208 E, $N_e - N_o = 0.0045$ D. Color orange red. Made from fusion with NaCl.

$SrMoO_4$ is tetragonal[11] with $c = 1.574$. Crystals pyramidal. G. = 4.15. Uniaxial positive. With 2.4 per cent $Ce_2(MoO_4)_3$: $N_o = 1.9088$, $N_e = 1.9127$, $N_e - N_o = 0.0039$ for 667 mμ; $N_o =$

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[11] F. Zambonini: *Bull. Soc. Fr. Min.*, XXXVIII, 1915, p. 206.

[12] Described as positive, but the indices make it negative.

1.9210, N_e = 1.9258, $N_e - N_o$ = 0.0048 for 570 mμ; N_o = 1.9290, N_e = 1.9350, $N_e - N_o$ = 0.0060 for 533 mμ. With 39.7 per cent $Ce_2(MoO_4)_3$: N_o = 1.937, N_e = 1.940, $N_e - N_o$ = 0.003 for 667 mμ; N_o = 1.952, N_e = 1.956, $N_e - N_o$ = 0.004 for 570 mμ; N_o = 1.958, N_e = 1.963, $N_e - N_o$ = 0.005 for 533 mμ. Color yellow. Made from fusion with NaCl at 1200° C.

$CaSO_4$ seems to have two crystal phases; the stable low temperature phase is orthorhombic with $a : b : c$ = 0.893 : 1 : 1.001. Crystals varied in habit with perfect 001 and 010 and distinct 100 cleavages. H. = 3. G. = 2.93. Soluble in HCl. Fuses at 1450° C. after inversion at 1195° C. The optic plane is 010; Z = a. On natural crystals:[13] (+) 2V = 42°, N_g = 1.614, N_m = 1.576, N_p = 1.571, $N_g - N_p$ = 0.043. Colorless. The natural substance, called *anhydrite*, is usually associated with halite and gypsum.

Anhydrite inverts at 1195° C. to a phase described as monoclinic,[14] which has lamellar twinning like plagioclase and [15] N_g = 1.56, N_m = ?, N_p = 1.50, $N_g - N_p$ = 0.06. Colorless. Unlike anhydrite this phase is soluble in water.

$BaSO_4$ is orthorhombic with $a : b : c$ = 0.815 : 1 : 1.314. Crystals nearly equant (with 011, 110, 001, 102, 100, 111) or 001 tablets bounded by 110, or columnar parallel to a or to b. See Figs. 229, 230. Perfect 001 and 110 and imperfect 010 cleavages with a prismatic cleavage angle of 78° 22′. Twinning on 100. H. = 3. G. = 4.5. Fuses at 1580° C. after inversion at 1149° C. Insoluble in acids. The optic

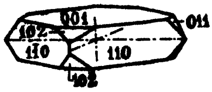

FIG. 229.

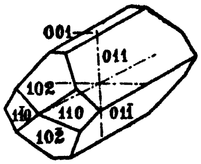

FIG. 230.

FIGS. 229, 230.—Crystal habits of $BaSO_4$, barite.

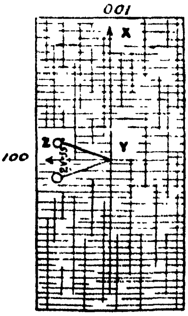

FIG. 231.—Optic orientation of $BaSO_4$, barite.

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[13] Very full data given by R. Kolb: *Zeit. Kryst.*, XLIX, 1911, p. 24.

[14] W. Grahmann: *Zeit. anorg. Chem.*, LXXXI, 1913, p. 257; *N. Jahrb. Min.*, 1920, I, p. 1.

[15] C Gaudefroy: *Bull. Soc. Fr. Min.*, XLII, 1919, p. 284.

plane is 010; Z = *a*. (+) 2V = 37° 28′ D; 2E = 62° 34′ C, 63° 12′ D, 64° 10′ E. Indices as measured by C. C. Wang at the University of Wisconsion on artificial crystals: N_g = 1.645 C, 1.647 D, 1.651 F, N_m = 1.634 C, 1.636 D, 1.641 F, N_p = 1.632 C, 1.634 D, 1.638 F; $N_g - N_p$ = 0.013 D. The natural substance is called *barite*.

$ZnSO_4$ is orthorhombic; crystals rectangular, or rhombic 001 plates. G. = 3.7. Alters on exposure to air. The optic plane is said to be 010, but X bisects acute angle (62°) of 001 plates of rhombic outline; Z = *c*. (−) 2V = small,[16] $\rho < v$ strong. N_g = 1.670, N_m = 1.669, N_p = 1.658, $N_g - N_p$ = 0.012. Made by dissolving zinc in concentrated H_2SO_4 and evaporating to dryness. Color white. The natural substance, known as *zinkosite*, is reported in Spain. Very rare.

$CuSO_4$ is orthorhombic with $a : b : c = 0.797 : 1 : 1.130$. Crystals tabular pseudohexagonal;[17] effloresces slowly in air, changing to chalcanthite. (−) 2V = large, $\rho > v$, extreme. N_g = 1.739, N_m = 1.733, N_p = 1.724, $N_g - N_p$ = 0.015. Color pale green, bluish white, etc. Impure crystals may be violet and pleochroic with Z = darkest violet. Recrystallization may give colorless crystals. Made from hot concentrated acid solution. The natural substance, known as *hydrokyanite*, is found at Vesuvius. Very rare.

$Pb_3Cr_2O_9$ (?) is probably orthorhombic with one perfect cleavage and tabular habit. H. = 3–3.5. G. = 5.75. Soluble in HCl. "Scarlet lead chromate" pigment is apparently this compound; in it X is parallel to the elongation[18] and Z is normal to the rectangular plates. (−) 2V = small; N_g = 2.57–2.62 Li, N_m = 2.57 Li, 2.7 Na, N_p = 2.42 Na. X = orange-yellow; Y, Z = orange-red.

$MgWO_4$ is monoclinic[19] and isomorphous with wolframite with $a : b : c = 0.826 : 1 : 0.870$, β = 89° 40′. The optic plane is 010 and extinction on 010 is at 4½°. 2V = large. Refringence very high; $N_g - N_p$ = extreme.

Cu_2SO_5 is monoclinic with $a : b : c = 1.323 : 1 : 1.203$, β = 71° 29′. Crystals elongated parallel to *b* with perfect 001 cleavage. Fusible. Soluble in HNO_3. The optic plane is 010; X is nearly normal to 001. (−) 2V = large, $\rho > v$ distinct. N_m = 1.777 ± 0.005, $N_g - N_p$ =

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[16] E. S. Larsen: *U. S. Geol. Surv. Bull.* 679, 1921, p. 159.

[17] H. E. Merwin: *Am. Mineral.*, VI, 1921, p. 125; E. Posnjak and G. Tunell: *Am. Jour. Sci.*, CCXVIII, 1929, p. 1.

[18] H. E. Merwin: *Proc. Am. Soc. Test. Mat.*, XVII, 1917, pt. 2.

[19] *Zeit. Kryst.*, LXVII, 1928, p. 163.

strong, as measured on crystals made by A. Vaughn Winchell by heating CuO and $CuSO_4$ in an earthenware crucible by means of thermite. Color brown with X or Z = lemon yellow, Y = orange to reddish brown. The natural substance, known as *dolerophanite*, forms as a sublimate at Vesuvius.

5. HYDROUS SULPHATES, ETC., OF DIVALENT BASES

$BeSO_4 \cdot 4H_2O$ is tetragonal with $c = 0.946$. Crystals pyramidal with no distinct cleavage. Twinning common on 101, cruciform or lamellar. G. = 1.73. Uniaxial negative with $N_o = 1.4691$ C, 1.4720 D, 1.4779 F, $N_e = 1.4374$ C, 1.4395 D, 1.4450 F, $N_o - N_e = 0.0325$ D. Wulff[20] gives $N_o - N_e = 0.0392$. Colorless. Made from H_2O solution. May take $BeSeO_4 \cdot 4H_2O$ in crystal solution up to 12 per cent with little effect on the properties.

$NiSO_4 \cdot 6H_2O$ is tetragonal with $c = 1.912$; crystals pyramidal, as in Fig. 232, or thick 001 tablets with perfect 001 cleavage. G. = 2.07. Uniaxial negative with $N_o = 1.5078$ C, 1.5109 D, 1.5173 F, $N_e = 1.4844$ C, 1.4873 D, 1.4930 F, $N_o - N_e = 0.0236$ D. Color emerald green. Made from H_2O solution at about 35° C. Crystallizing from solution at about 60° C., the form is monoclinic with $a : b : c = 1.372 : 1 : 1.676$, $\beta = 81° \ 43'$; crystals prismatic basal tablets without cleavage; the optic plane is 010; X is nearly normal to $\bar{1}02$ or $X \wedge c = 26° \ 17'$; (−) $2H = 19° \ 25'$, $\rho > v$; color emerald green.

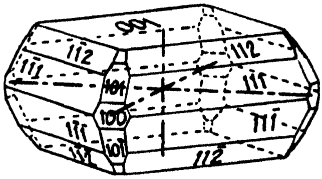

FIG. 232.—Unit and diametral pyramids and base; $NiSO_4 \cdot 6H_2O$.

$CoSO_4 \cdot 6H_2O$ is probably tetragonal, being uniaxial[21] negative with $N_o = 1.495$, $N_e = 1.460$, $N_o - N_e = 0.035$. Blue in mass; faintly pleochroic in pink. The same compound is monoclinic when crystallized at about 45° C. from H_2O solution. Crystals prismatic with 001. G. = 2.0. The optic plane is 010, X is nearly normal to $\bar{1}02$. (−) $2H = 8°$, $\rho > v$ with weak inclined dispersion.

$NiSeO_4 \cdot 6H_2O$ is tetragonal with $c = 1.836$; crystals from cold solutions are basal tablets and from hot solutions are acute pyramidal with perfect 001 cleavage. G. = 2.31. Uniaxial negative with $N_o = 1.5357$ C, 1.5393 D, 1.5473 F, $N_e = 1.5089$ C, 1.5125 D, 1.5196 F, $N_o - N_e = 0.0268$ D. Made from H_2O solution.

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[20] *Zeit. Kryst.*, XVII, 1890, p. 592.

[21] E. S. Larsen and M. L. Glenn: *Am. Jour. Sci.*, CC, 1920, p. 225.

$ZnSeO_4 \cdot 6H_2O$ is tetragonal with c = 1.895, of similar habit, with perfect 001 cleavage. G. = 2.33. Uniaxial negative with N_o = 1.5255 C, 1.5291 D, 1.5367 F, N_e = 1.5004 C, 1.5039 D, 1.5108 F, $N_o - N_e$ = 0.0183 D. Colorless. Made from H_2O solution at about 15° C.

$CaSO_4 \cdot \frac{1}{2}H_2O$ is probably hexagonal;[15] crystals six-sided prisms with G. = 2.55. Uniaxial positive with N_o = 1.55 or slightly less, N_e = 1.57, $N_e - N_o$ = 0.02 or slightly more. Colorless. As made by partial dehydration of gypsum at about 120° C. it is acicular with silky luster. According to Ramsdell and Partridge[22] most of the water can be expelled by heat from $CaSO_4 \cdot \frac{1}{2}H_2O$ without destroying the crystal structure and without essentially changing the properties; such dehydrated material will take on water again at the first opportunity just as dehydrated zeolites will; such dehydrated material is different in crystal structure and optical properties from anhydrite ($CaSO_4$); it should therefore be called *dehydrated hemihydrate* rather than "soluble anhydrite." $CaSO_4 \cdot \frac{1}{2}H_2O$ is *plaster of Paris.*

$BeSeO_4 \cdot 4H_2O$ is orthorhombic with $a : b : c$ = 0.960 : 1 : 0.903. Crystals macrodomatic columnar with no good cleavage. Cruciform twinning on 110. G. = 2.03. The optic plane is 100; X = c. (−) 2V = 26° 43′. N_g = 1.4992 C, 1.5027 D, 1.5101 F, N_m = 1.4973 C, 1.5007 D, 1.5084 F, N_p = 1.4637 C, 1.4664 D, 1.4725 F, $N_g - N_p$ = 0.0363 D. Colorless. Made from H_2O solution. May take $BeSO_4 \cdot 4H_2O$ in crystal solution to at least 60 per cent with very little change in optic properties.

$MgSO_4 \cdot 7H_2O$ is dimorphous; the usual phase is orthorhombic sphenoidal with $a : b : c$ = 0.99 : 1 : 0.57. Crystals usually prismatic terminated by one (or more) sphenoids. See Figs. 233, 234. H = 2.5. G. = 1.68. Distinct 010 and indistinct 101 cleavages. Soluble in H_2O. The optic plane is 001; X = b. (−) 2V = 51° 25′, $\rho > v$ weak. N_g = 1.4583 C, 1.4608 D, 1.4657 F, N_m = 1.4530 C, 1.4554 D, 1.4607 F, N_p = 1.4305 C, 1.4325 D, 1.4374 F, $N_g - N_p$ = 0.0283 D. Rotates the plane of polarization 2.6° (per mm. thickness) for Na light. Colorless. The natural substance is known as *epsomite.*

Orthorhombic $MgSO_4 \cdot 7H_2O$ is miscible in all proportions with $NiSO_4 \cdot 7H_2O$ with rectilinear variation of N_m.[23] It is also miscible in all proportions with $ZnSO_4 \cdot 7H_2O$ with rectilinear variation of all three indices of refraction[24] (in terms of volume or molecular composition).

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[22] *Am. Mineral.*, XIV, 1929, p. 59.

[23] Dufet: *Bull. Soc. Fr. Min.*, I, p. 58.

A second phase of $MgSO_4 \cdot 7H_2O$ is monoclinic with $a : b : c = 1.22 : 1 : 1.58$, $\beta = 75° \; 36'$. Crystals pseudorhombohedral and isomorphous with $FeSO_4 \cdot 7H_2O$, with which it is miscible probably in all proportions and certainly to at least 40 per cent, but optic data are lacking.

$NiSO_4 \cdot 7H_2O$ is orthorhombic sphenoidal with $a : b : c = 0.982 : 1 : 0.566$. Crystals columnar to fibrous prismatic aggregates with perfect 010 cleavage. H. = 2–2.5. G. = 1.95. F. = 7. The optic plane is 001; X = *b*. (−) $2V = 41° \; 54'$, $\rho > v$ weak. $N_g = 1.4923$ D, $N_m = 1.4893$, $N_p = 1.4693$, $N_g - N_p = 0.023$. Also $N_g = 1.4921$ D, $N_m = 1.4888$ D, 1.4949 F, $N_p = 1.4669$ D, $N_g - N_p = 0.0252$ D. Color apple green. Made from H_2O solution. The natural substance, called *morenosite*, occurs as an efflorescence on nickel sulphide ores; rare.

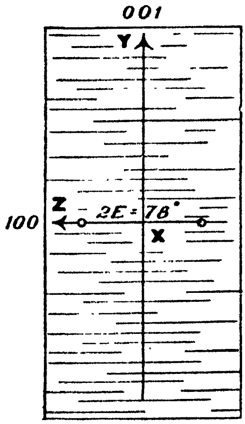

FIG. 235.—Optic orientation of $MgSO_4 \cdot 7H_2O$.

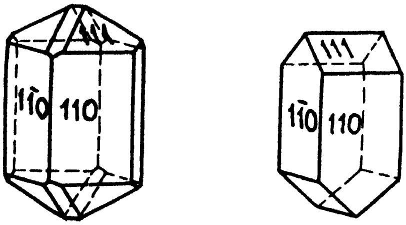

FIG. 233. FIG. 234.

FIGS. 233, 234.—Crystal habits of $MgSO_4 \cdot 7H_2O$.

$ZnSO_4 \cdot 7H_2O$ is orthorhombic with $a:b:c = 0.981 : 1 : 0.563$. Crystals acicular to hair-like in tufts with perfect 010 cleavage. H. = 2. G. = 2.0. Dehydrates in dry air. The optic plane is 001; X = *b*. (−) $2V = 46° \; 14'$, $\rho > v$ weak. $N_g = 1.4812$ C, 1.4836 D, 1.4897 F, $N_m = 1.4776$ C, 1.4801 D, 1.4860 F, $N_p = 1.4544$ C, 1.4568 D, 1.4620 F, $N_g - N_p = 0.0268$ D. Colorless. Made from H_2O solution below 30° C. Miscible in all proportions with $MgSO_4 \cdot 7H_2O$. The natural substance, called *goslarite*, forms by oxidation and hydration of sphalerite, being precipitated from solution by evaporation in mine galleries; rare.

$(Zn, Fe)SO_4 \cdot 7H_2O$ with Zn : Fe = 2 : 1 is biaxial[25] and orthorhombic (?) with (+) 2V = 78° 48′, $N_g = 1.4867$, $N_m = 1.4785$, $N_p = 1.4709$, $N_g - N_p = 0.0158$.

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[24] M. W. Porter: *Zeit. Kryst.*, LXXV, 1930, p. 288.

[25] C. Andreatta: *Atti R. Accad. Lincei, Cl. Sci.* 6, XI, 1930, p. 760.

$MgCrO_4 \cdot 7H_2O$ is orthorhombic sphenoidal with $a : b : c = 0.990 : 1 : 0.574$. Crystals columnar prismatic with perfect 010 cleavage. G. = 1.69. The optic plane is 001; X = *b*. (−) 2V = 75° 28′, $\rho < v$. $N_g = 1.5633$ C, 1.5680 D, $N_m = 1.5415$ C, 1.5500 D, $N_p = 1.5131$ C, 1.5211 D, $N_g - N_p = 0.0469$ D. Made from H_2O solution.

$3CuO \cdot SO_3 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.504 : 1 : 0.687$. Crystals domatic with perfect 010 cleavage. H. = 3. G. = 3.9. The optic plane is 001; X = *b*; optic axes nearly normal to the prism faces. (+) 2V = 53° (indices),[26] $\rho < v$ strong. $N_g = 1.789$, $N_m = 1.738$, $N_p = 1.726$, $N_g - N_p = 0.063$. Green with X = yellowish-green, Y = bluish-green, Z = green. The natural substance is called *antlerite.*

$4CuO \cdot SO_3 \cdot 3H_2O$ is orthorhombic with $a : b : c = 0.774 : 1 : 0.487$. Crystals prismatic, vertically striated, with perfect 010 cleavage. H. = 4. G. = 3.9. F. = 3.5. Soluble in HNO_3. The optic plane is 100; X = *b*; positive elongation. (−) 2V = 77° (from indices),[26] $\rho < v$ moderate. $N_g = 1.800$, $N_m = 1.771$, $N_p = 1.728$, $N_g - N_p = 0.072$. Color emerald green with X = bluish-green (Ridgway's 39′d), Y and Z = bluish-green (Ridgway's 37′d). Artificial crystals determined by measuring indices. The natural substance is called *brochantite.*

$MgSO_4 \cdot H_2O$ is monoclinic with $a : b : c = 0.915 : 1 : 1.745$, β = 88° 53′. Crystals acute pyramidal with perfect $11\bar{1}$ and $11\bar{3}$ and less distinct 111, 101, and 012 cleavages. H. = 3.5. G. = 2.57. Slowly soluble in H_2O. The optic plane is 010; $Z \wedge c$ = +76° 25′. (+) 2E = 90° 42′ red, 90° 0′ yellow, 89° 16′ blue. 2V = 57°, $\rho > v$ distinct. Artificial crystals [27] identified by optic measures. $N_g = 1.586$, $N_m = 1.535$, $N_p = 1.523$, $N_g - N_p = 0.063$ (nat. cryst.). Colorless. The natural substance is called *kieserite.*

$MnSO_4 \cdot H_2O$ is probably monoclinic with one perfect cleavage. H. = 1.5. G. = 3.15. F. = 7. The optic plane and Z are normal to 010; $Y \wedge c$ = large, with marked dispersion. Negative elongation. (+) 2V [21] = nearly 90°. $N_g = 1.632$, $N_m = 1.595$, $N_p = 1.562$, $N_g - N_p = 0.070$. Color white to pink. Made from solution. The natural substance, called *szmikite,* has $N_g = 1.62$, N_m = ?, $N_p = 1.57$ as found in Hungary.

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[26] E. Posnjak and G. Tunell: *Am. Jour. Sci.*, CCXVIII, 1929, p. 1.

[27] W. C. Blasdale and H. L. Robson: *Jour. Am. Chem. Soc.*, L, 1928, p. 35.

$CoSO_4 \cdot H_2O$ is probably monoclinic, having incl'ned extinction. $(-)$ $2V$ = nearly 90°, $N_g = 1.683$, $N_m = 1.639$, $N_p = 1.603$, $N_g - N_p = 0.080$ as formed in a desiccator[28] from $CoSO_4 \cdot 6H_2O$. The monohydrate formed by evaporation on a steam bath has $N_g = 1.645$, $N_p = 1.600$ and negative elongation.

$CuSO_4 \cdot H_2O$ is biaxial,[26] but of unknown symmetry. $(-)$ $2V = 75°$ (indices), $\rho < v$. $N_g = 1.699$, $N_m = 1.671$, $N_p = 1.626$, $N_g - N_p = 0.073$. Bluish-white in mass; colorless in section.

$MgSO_4 \cdot 5/4H_2O$ is probably monoclinic[29] in twinned diamond-shaped crystals with $N_g = ?$, $N_m = 1.530$, $N_p = 1.512$. Colorless.

$MgSO_4 \cdot 2H_2O$ forms fine radiated masses[29] with $N_m = 1.493$. A substance given as **$MgSO_4 \cdot 3H_2O$** (?) is perhaps the same. It is biaxial negative[30] with $N_m = 1.490 \pm$.

$CaSO_4 \cdot 2H_2O$ is monoclinic with $a : b : c = 0.6899 : 1 : 0.4124$, $\beta = 80° 42'$; crystals usually simple in habit, commonly tabular parallel to 010 as in Fig. 236 or prismatic to acicular parallel to c with perfect 010 and imperfect 100 and $\bar{1}11$ cleavages. Twinning on 100 common in arrow-head forms, as in Fig. 237. H. = 2. G. = 2.32. F. = 2.5–3. Soluble in HCl. The optic plane is parallel with 010 at ordinary temperatures with $Z \wedge c = +52\frac{1}{2}°$. The optic angle varies

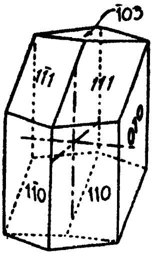

FIG. 236.—A crystal habit of $CaSO_4 \cdot 2H_2O$.

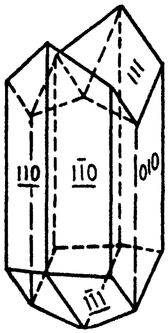

FIG. 237.—Gypsum crystal twinned on 100.

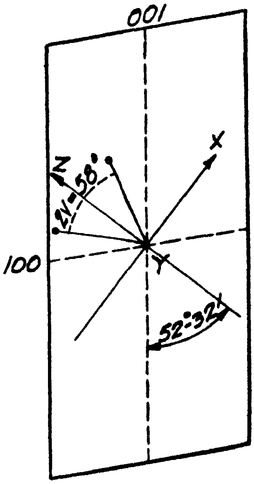

FIG. 238.—Optic orientation of $CaSO_4 \cdot 2H_2O$, gypsum.

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[28] E. S. Larsen and M. L. Glenn: *Am. Jour. Sci.*, CC, 1920, p. 225. The indices require a *positive* sign.

[29] H. L. Robson: *Jour. Am. Chem. Soc.*, XLIX, 1927, p. 2772.

[30] E. V. Shannon: *Proc. U. S. Nat. Mus.*, LXXIV, 1928, Art. 13.

rapidly with the temperature from about 95° for 2E at 20° C to 0° at about 91° C. and an optic angle in a plane normal to 010 at higher temperatures; at the same time the dispersion changes from $\rho > v$ with strong inclined dispersion at 20° C. to $\rho < v$ with horizontal dispersion at 120° C. (+) 2V = 58° 5′ Na, $N_g = 1.5296$, $N_m = 1.5226$, $N_p = 1.5205$, $N_g - N_p = 0.0091$. Colorless. It loses three-fourths of its water at 128° C. (forming "*plaster of Paris*" which has [16] $N_o = 1.55 \pm$, $N_e = 1.57$, $N_e - N_o = 0.02$) and the remainder above 163° C.; when heated above this temperature is apt to be "dead-burned" and not useful as plaster; such material has $N_o = 1.50$, $N_e = 1.56$, $N_e - N_o = 0.06$. Natural $CaSO_4 \cdot 2H_2O$ is known as *gypsum*; in nature it may dehydrate to anhydrite or be formed by hydration of the latter. Gypsum forms occasional extensive beds in sedimentary rocks, especially with limestone; it is often associated with halite as a product of evaporation of salt lakes, estuaries, etc. It is also found about volcanoes. It may be formed by the decomposition of sulphides, such as pyrite, in the presence of lime. It has characteristic crystal forms, one perfect cleavage, is soft and hydrous, and has slight negative relief, weak birefringence, and strong inclined dispersion about the positive bisectrix of the medium optic angle.

$CdSO_4 \cdot 8/3H_2O$ is monoclinic with $a : b : c = 0.799 : 1 : 0.690$, $\beta = 62° 2'$. Crystals 001 plates more or less elongated parallel to a with perfect 010 cleavage. G. = 3.05. The optic plane and axis X are normal to 010; $Z \wedge c = +76° 14'$ red, 77° 3′ blue; (−) 2V = 87° 57′ red, 88° 9′ Na, 88° 23′ blue, $\rho > v$ weak; $N_m = 1.563$ red, 1.565 Na, 1.576 blue, $N_g - N_p = ?$ Made from H_2O solution.

$CuSO_4 \cdot 3H_2O$ is monoclinic [26] with $a : b : c = 0.432 : 1 : 0.552$, $\beta = 83° 35'$. Crystals short prismatic with distinct 010 cleavage and 100 twinning. Optic orientation unknown. (+) 2V = 75° (indices) without perceptible dispersion. $N_g = 1.618$, $N_m = 1.577$, $N_p = 1.554$. $N_g - N_p = 0.064$. Blue; colorless in section.

$MgSO_4 \cdot 4H_2O$ is monoclinic with $a : b : c = 0.45 : 1 : ?$, $\beta = 89° 49'$. Crystals short prismatic with good 100 and 010 cleavages.[29] Optic plane and Z normal to 010; $X \wedge c = +81°$. Strong horizontal dispersion. (+) 2V = 50°, $\rho > v$. $N_g = 1.497$, $N_m = 1.491$, $N_p = 1.490$, $N_g - N_p = 0.007$. The angle $110 : 1\bar{1}0 = 48° 40'$ is observed readily.

$FeSO_4 \cdot 4H_2O$ is monoclinic [31] with $a : b : c = 0.438 : 1 : 0.587$,

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[31] R. Scharizer: *Festschr. V. Goldschmidt*, 1928, p. 263; *N. J. Min.*, 1928, I, p. 302.

$\beta = 89° 29'$. Crystals short prismatic with rather perfect 010 cleavage. Distinct striations on 001 and 011. G. = 2.28. The optic plane and Z are normal to 010. (−) 2V = very large. Horizontal dispersion. $N_g = ?$, $N_m = 1.535$, $N_p = 1.533$, $N_g - N_p = ?$ Color pale green. Made from H_2O solution at about 80° C.

$MnSO_4 \cdot 4H_2O$ is monoclinic with $a : b : c = 0.432 : 1 : 0.582$, $\beta = 89° 7'$. Crystals short prismatic or 001 plates elongated parallel to a. Perfect 010 cleavage. G. = 2.26. The optic plane is 010; $Z \wedge a = 5°$, $Z \wedge c = +85° 48'$ Li, 84° 8′ blue. (−) 2E = 105° 45′ Na, $\rho > v$ weak; 2V = 63°. $N_g^{16} = 1.522$, $N_m = 1.518$, $N_p = 1.508$, $N_g - N_p = 0.014$. Color pink. Made from **H_2O solution at about** 45° C.

$MgSO_4 \cdot 6H_2O$ is monoclinic with $a : b : c = 1.404 : 1 : 1.668$, $\beta = 81° 26'$. Crystals thick 001 tablets or prismatic with 110 cleavage. G. = 1.75. F. = 7, but exfoliates. The optic plane[17a] is 010; $X \wedge c = -25°$; X is nearly normal to $\bar{1}02$. (−) 2H = 28°, $\rho > v$; 2V = 29° ±. $N_g = 1.465$, $N_m = 1.463$, $N_p = 1.438$, $N_g - N_p = 0.027$. Color white, slightly greenish. Made from H_2O solution above 35° C. The natural substance, called *hexahydrite*, is very rare.

$MgSeO_4 \cdot 6H_2O$ is monoclinic with $a : b : c = 1.385 : 1 : 1.685$, $\beta = 81° 28'$. Crystals thick basal tablets with perfect $10\bar{1}$ cleavage. G. = 1.93. The optic plane is 010; $X \wedge c = -27°$. (−) 2V = 28° 12′, $\rho > v$ strong. $N_g = 1.4911$ D, $N_m = 1.4864$ C, 1.4892 D, 1.4965 F, $N_p = 1.4856$, $N_g - N_p = 0.0055$. Made from H_2O solution at ordinary temperature.

$CoSeO_4 \cdot 6H_2O$ is monoclinic with $a : b : c = 1.371 : 1 : 1.682$, $\beta = 81° 46'$. Crystals thick 001 tablets or short prismatic with perfect $10\bar{1}$ cleavage. G. = 2.18. The optic plane is 010; $X \wedge c = -34° 42'$. (−) 2V = 7° 13′, $\rho > v$, $N_g = 1.5227$ Na, $N_m = 1.5183$ Li, 1.5225 Na, $\therefore N_p = 1.47$ and $N_g - N_p = 0.05$. Made from **H_2O solution** above 15° C.

$FeSO_4 \cdot 7H_2O$ is monoclinic with $a : b : c = 1.183 : 1 : 1.543$, $\beta = 75° 45'$. Crystals nearly equant as in Fig. 239 and varied with perfect 001 and distinct 110 cleavages. H. = 2. G. = 1.90. F. = easy. Dehydrates in dry air. The optic plane is 010; $Z \wedge c = -62°$. (+) 2V = 85° 27′, $\rho > v$ weak with weak inclined dispersion.[32] $N_g = 1.4824$ Li, 1.4856 Na, $N_m = 1.4748$ Li, 1.4782 Na, 1.4861 blue, $N_p = 1.4681$ Li, 1.4713 Na, $N_g - N_p = 0.0143$ Na. Color green to white; becomes yellow by alteration to copiapite. The natural substance, called *melanterite,* is formed by oxidation and hydration of iron sulphide.

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[32] *Sitz. Akad. Wiss. Wien*, LVI, 2, 1867, p. 63.

(Fe, Cu) $SO_4 \cdot 7H_2O$ is monoclinic with $a:b:c = 1.61:1:1.511$, $\beta = 74° 38'$. Crystals tabular with perfect 001 cleavage. H. = 2.5. G. = 1.9. F. = 3.5. Loses water in dry air. Optic plane is 010; $X \wedge c = +22°$. (+) 2V = very large with weak dispersion. Crystals may show hour-glass structure. $N_g = 1.487$, $N_m = 1.479$, $N_p = 1.472$, $N_g - N_p = 0.015$. Color pale blue. Made from H_2O solution at 4° C. The natural substance, called *pisanite,* is found in copper mines. Rare.

$CuSO_4 \cdot 7H_2O$ is monoclinic with $a:b:c = 1.162:1:1.500$, $\beta = 74° 24'$. Crystals fibrous with 001 cleavage. H. = 2.5. G. = 1.94. Unstable under ordinary conditions, changing to chalcanthite. Optic plane is 010; Z near *a*. Biaxial positive with indices very near those of pisanite. Optic sign negative (Lacroix).[33] Color pale blue; colorless in section. The natural substance, called *boothite,* is found in copper mines having damp air. Very rare.

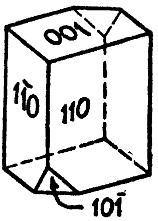

FIG. 239.—A crystal habit of $FeSO_4 \cdot 7H_2O$.

$CoSO_4 \cdot 7H_2O$ is monoclinic with $a:b:c = 1.182:1:1.533$, $\beta = 75° 20'$. Crystals complex tabular parallel to 101̄. Perfect 001 and distinct 110 cleavages. H. = 2. G. = 1.96. F. = easy. Loses water in dry air. The optic plane is 010 (Lacroix);[33] $X \wedge c = +29° 18'$ (Porter).[34] (−) $2V = 88°$, $\rho < v$, weak. $N_g = 1.489$, $N_m = 1.483$, $N_p = 1.477$, $N_g - N_p = 0.012$ (Larsen).[16] Also $N_g = 1.4885$ Na, $N_m = 1.4820$, $N_p = 1.4748$, $N_g - N_p = 0.0137$ (Porter).[34] Color carmine, slightly pleochroic in pink tints. Made from H_2O solution at 23° C. The natural substance, called *bieberite,* is found about mines. Very rare.

$3CuO \cdot 2SO_3 \cdot 5H_2O$ is triclinic[26] with $a:b:c = 0.78:1:1.076$, $\alpha = 103° 4'$, $\beta = 99° 7'$, $\gamma = 104° 48'$. Crystals prismatic tabular with perfect 010 and 001 and good 100 and 1̄01 cleavages. $Z' \wedge c = +19\frac{1}{2}°$ on 010; $Z' \wedge a = +27°$ on 001. (−) $2V = 87°$ (indices), $\rho > v$ extreme. $N_g = 1.641$, $N_m = 1.623$, $N_p = 1.601$, $N_g - N_p = 0.040$. Green with X = greenish-yellow, Y = green, Z = bluish-green.

$MgSO_4 \cdot 5H_2O$ is triclinic with $a:b:c = 0.602:1:0.561$, $\alpha = 81° 30'$, $\beta = 109° 0'$, $\gamma = 104° 55'$. Crystals vertically elongated with

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[33] *Mineral. France,* IV, 1910, p. 227.

[34] *Festsch. V. Goldschmidt,* 1928, p. 210.

100 and $11\bar{1}$ prominent but with no distinct cleavage. G. = 1.72. Unstable in air. The optic plane[29] and X are nearly normal to 010; (−) 2V = 45° 8′, $\rho < v$. $N_g = 1.493$, $N_m = 1.492$, $N_p = 1.482$, $N_g - N_p = 0.011$. Colorless. Made from H_2SO_4 solution.

$CuSO_4 \cdot 5H_2O$ is triclinic with $a : b : c = 0.572 : 1 : 0.557$, and $\alpha = 97° 44'$, $\beta = 107° 26'$, $\gamma = 100° 40'$, Tutton.[35] Crystals commonly short prismatic, as in Fig. 240, flattened parallel to $11\bar{1}$ with imperfect 110, $1\bar{1}0$ and $11\bar{1}$ cleavages. H. = 2.5. G. = 2.28. F. = 3. The negative acute bisectrix X lies between $+a$, $-b$, and $+c$; according to Pape it makes angles[36] of 98½°, 43¾°, and 73° with normals to 110, $1\bar{1}0$ and $11\bar{1}$. According to Wulff[37] γ makes angles of 12½°, 53½°, and 67° with normals to 110, $1\bar{1}0$, and $11\bar{1}$. Z makes angles[38] of 12½°, 46¾°, and 46¼° with normals to the same faces. Crystals formed on a glass slide by evaporation of an aqueous solution all lie[38] on the face $\bar{1}10$ (or $1\bar{1}0$), the plane angle of which is 57°; the crystals are oblique to an optic axis; the optic plane makes an angle of 75° with one side of the rhomb in the obtuse angle thereof. (−) 2V = 56° 2′, $\rho < v$ weak with crossed and strong inclined dispersion. N_g[39] = 1.5431, $N_m = 1.5381$, $N_p = 1.5120$, $N_g - N_p = 0.0311$. According to Merwin[40] $N_g = 1.5434$ D, $N_m = 1.5337$ C, 1.5368 D, 1.5438 F, $N_p = 1.5141$, $N_g - N_p = 0.0293$ D. Color blue; nearly colorless in section. Made from H_2O solution. The natural substance, called *chalcanthite*, forms by alteration of copper ores.

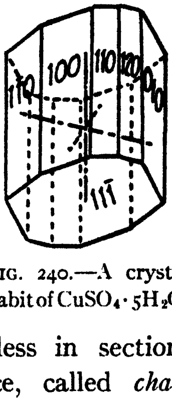

FIG. 240.—A crystal habit of $CuSO_4 \cdot 5H_2O$.

$FeSO_4 \cdot 5H_2O$ is triclinic[21] with $a : b : c = 0.596 : 1 : 0.577$, $\alpha = 81° 23'$, $\beta = 110° 28'$, $\gamma = 105° 33'$. Crystals short prismatic to acicular. H. = 2–3. G. = 2.2. F. = 3. (−) 2V = moderate, $\rho > v$ weak. $N_g = 1.542$, $N_m = 1.536$, $N_p = 1.526$, $N_g - N_p = 0.016$. Color bluish green, pale green, white. Made from H_2O solution. The natural substance, called *siderotil*, is a common alteration product of melanterite.

$(Zn, Cu)SO_4 \cdot 5H_2O$ is similar[21] G. = 2.1. (−) 2V = moderate.

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[35] The orientation used here is that of Tutton modified by rotation of 180° on an axis normal to 010 so that the *b* axis may incline downward to the *right*.

[36] *Pogg. Ann. Erg. Bd.*, VI, p. 35; *Int. Crit. Tab.*, VII, 1930, p. 21.

[37] Groth: *Chem. Kryst.*, II, 1908, p. 420.

[38] J. Melon: *Bull. Soc. Fr. Min.*, XLVII, 1924, p. 141.

[39] L. Weber: *Tables Ann. Inter. Const.*, V, 1923.

[40] *Int. Crit. Tables*, VII, 1930, p. 21.

$N_g = 1.540^\circ$, $N_m = 1.533$, $N_p = 1.513$, $N_g - N_p = 0.027$. Color pale blue; nearly colorless in section.

$CoSO_4 \cdot 5H_2O$ is similar.[21] H. = 2–3. G. = 2.2. F. = 3. (–) 2V = moderate, dispersion not strong, $N_g = 1.550$, $N_m = 1.548$, $N_p = 1.530$, $N_g - N_p = 0.020$. Color rose-pink. Made from H_2O solution.

$MnSO_4 \cdot 5H_2O$ is triclinic[21] with $a : b : c = 0.589 : 1 : 0.569$, $\alpha = 81^\circ\ 37'$, $\beta = 110^\circ\ 5'$, $\gamma = 104^\circ\ 59'$. Crystals nearly equant, acicular parallel to c, or lamellar parallel to 100. Imperfect 011 cleavage. H. = 2–3. G. = 2.1. F. = 3. Y nearly normal to plates in which extinction is at 15° to length. (–) 2V = rather large, with $\rho > v$. $N_g = 1.514$, $N_m = 1.508$, $N_p = 1.495$, $N_g - N_p = 0.019$. Color pale pink. Made from H_2O solution at 23° C. in a desiccator under reduced pressure.

$CuSeO_4 \cdot 5H_2O$ is triclinic with $a : b : c = 0.568 : 1 : 0.555$, $\alpha = 98^\circ\ 2'$, $\beta = 106^\circ\ 34'$, $\gamma = 103^\circ\ 11'$. Crystals short prismatic, vertically striated like chalcanthite. G. = 2.56. Bolland[41] measured on "copper selenate" of unknown formula: $N_1 = 1.565$, $N_2 = 1.56$; sign –, and extinction angle = 34°. Color red. Made from H_2O solution.

6. ANHYDROUS SULPHATES, ETC., OF TRIVALENT BASES

$Nd_2(MoO_4)_3$ is tetragonal[11] with $c = 1.548$. Crystals pyramidal. G. = 5.14. F. = 1176° C. Uniaxial negative with $N_o = 2.0052$, $N_e = 2.0038$ for 667 mμ; $N_o = 2.0239$, $N_e = 2.0218$, $N_o - N_e = 0.0021$ for 570 mμ; $N_o = 2.0313$, $N_e = 2.0293$ for 533 mμ. Color violet. Made from fusion.

$Pr_2(MoO_4)_3$ is tetragonal[11] with $c = 1.544$. Crystals pyramidal. G. = 4.84. F. = 1030° C. Uniaxial negative with $N_e = 1.990$ for 667 mμ, 2.007 for 570 mμ, and 2.016 for 533 mμ, $N_o - N_e$ = weak. Color grass green. Made from fusion.

$Di_2(MoO_4)_3$ is tetragonal[11] with $c = 1.549$. Crystals pyramidal or 001 tablets. G. = 4.96. F. = 1125° – 1144° C. Uniaxial negative with N = 2.008 B, 2.026 D, 2.039 E, $N_o - N_e$ = weak. Made from fusion.

$Y_2(MoO_4)_3$ is tetragonal[11] with $c = 1.542$. Crystals pyramidal with 001. Distinct 001 cleavage. G. = 4.79. F. = 1347° C. Uniaxial positive with $N_e = 2.013$ for 667 mμ, 2.031 for 570 mμ, and 2.043 for 533 mμ, $N_e - N_o$ = very weak. Also slightly biaxial with 2E = 10°

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[41] *Sitz. Akad. Wiss. Wien*, CXIX, 1910, p. 275.

or less. Also orthorhombic with perfect 001 and distinct 110 cleavages. Color white or yellowish. Made from fusion.

$Ce_2(MoO_4)_3$ is tetragonal[11] above 900° C. with $c = 1.562$. Crystals pyramidal. G. = 5.03. F. = 970° ± C. Uniaxial negative with $N_o = 2.0185$, $N_e = 2.0067$ for 667 mμ; $N_o = 2.0403$, $N_e = 2.0277$, $N_o - N_e = 0.0126$ for 570 mμ; $N_o = 2.0512$, $N_e = 2.0375$ for 533 mμ. Color orange to red; yellow in powder. Made by heating to about 900° C. Metastable at 0° C., the stable form being orthorhombic and dark green, not measured optically.

$Fe_2(SO_4)_3$ is rhombohedral[42] with $c = 1.35$. Crystals flattened rhombohedrons with rhombohedral cleavage. Stable above 130° C. Uniaxial negative with $N_o = 1.756$ C, 1.770 D, 1.809 F, $N_e = 1.746$ C, 1.760 D, 1.798 F, $N_o - N_e = 0.010$ D. Colorless or grayish yellow. Made in a steel bomb at moderate temperatures.

$Fe_2(SO_4)_3$ is also orthorhombic[42] with $a : b : c = 0.957 : 1 : 1.357$. Crystals 001 tablets bounded by 010, 110, 111, 101 and 100. Stable above 130° C. The optic plane is 100; $X = c$. (−) $2V = 60°$, $N_g = 1.803$ C, 1.818 D, 1.861 F, $N_m = 1.799$ C, 1.814 D, 1.857 F, $N_p = 1.787$ C, 1.802 D, 1.844 F, $N_g - N_p = 0.016$ D. Color grayish yellow. Made in a steel bomb at moderate temperature.

7. HYDROUS SULPHATES, ETC., OF TRIVALENT BASES

$Cr_2(SO_4)_3 \cdot 18H_2O$, as obtained commercially, is granular and apparently amorphous with[43] $N = 1.564 \pm 0.003$ Na. Color dark green. No crystals were obtained by evaporation of a solution of the salt and no X-ray pattern was obtained using the powder method.

$La_2(SO_4)_3 \cdot 9H_2O$ is hexagonal with $c = 0.736$. Crystals long prismatic without cleavage. G. = 2.82. Uniaxial positive with $N_o = 1.564$, $N_e = 1.569$, $N_e - N_o = 0.005$. Made from solution.

$3Fe_2O_3 \cdot 4SO_3 \cdot 9H_2O$ is rhombohedral[42] with $c = 1.14$. Crystals rhombohedral (nearly cubic) with no good cleavage. Uniaxial negative with $N_o = 1.799$ C, 1.816 D, 1.865 F, $N_e = 1.718$ C, 1.728 D, 1.755 F, $N_o - N_e = 0.088$ D. Color orange yellow with X = clear yellow, Z = dark yellow. Closely related to, if not identical with, *carphosiderite*. Made by heating a 25 per cent solution of ferric sulphate to 150° C.

$Fe_2O_3 \cdot 2SO_3 \cdot H_2O$ is orthorhombic;[42] crystals prismatic fibrous.

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[42] E. Posnjak and H. E. Merwin: *Jour. Am. Chem. Soc.*, XLIV, 1922, p. 1965. Also R. Scharizer: *Zeit. Kryst.*, LXV, 1927, p. 335.

[43] V. A. Vigfusson—personal communication, Dec. 18, 1930.

Z parallel to elongation. (+) 2V = small. N_g = 1.897 C, 1.918 D, 1.968 F, N_m = 1.790 C, 1.804 D, 1.844 F, N_p = 1.772 C, 1.783 D, 1.814 F, $N_g - N_p$ = 0.135 D. Color orange yellow with X and Y = colorless, Z = clear yellow. Made in a steel bomb. Stable above about 80° C. to at least 200° C.

$Fe_2O_3 \cdot 4SO_3 \cdot 9H_2O$ is orthorhombic with $a : b : c = 0.563 : 1$ 0.940. Crystals platy with perfect basal and distinct prismatic cleavages. The optic plane is 100. X = *c*. (+) 2V = small. N_g = 1.626 C,[42] 1.635 D,[44] 1.657 F, N_m = 1.545 C, 1.550 D, 1.564 F, N_p = 1.529 C, 1.533 D, 1.545 F, $N_g - N_p$ = 0.102 D. Color red with X = light purple, Y = Z = very clear yellow, colorless or pink. Loses water in stages over sulphuric acid. Deliquesces in moist air. Made from solution. The natural substance, called *rhomboclase*, is found in Hungary. Very rare.

$2Fe_2O_3 \cdot 5SO_3 \cdot 17(?)H_2O$ is orthorhombic with $a : b : c = 0.81 : 1 : ?$; crystals tabular with distinct 010 and 001 cleavages. H. = 2.5. G. = 2.1–2.2. F. = 4.5–5. The optic plane is 010; X = *c*. (+) 2V = 52°, N_g = 1.589 C, 1.597 D, 1.620 F, N_m = 1.541 C, 1.546 D, 1.559 F, N_p = 1.527 C, 1.531 D, 1.542 F, $N_g - N_p$ = 0.066 D. Color greenish yellow with X = colorless, Y = light grayish yellow, Z = bright yellow. Made from H_2O solution below 90° C. The crystals appear to be monoclinic due to unequal development of prism faces. They may undergo considerable dehydration without apparent change of identity; this raises the indices about 0.04. The natural substance, called *copiapite*, is an alteration product of iron sulphide and of melanterite.

$Fe_2O_3 \cdot 2SO_3 \cdot 5H_2O$ is monoclinic[42] with $a : b : c = 0.858 : 1 : 1.358$, $\beta = 71° 24'$. Crystals prismatic with good 001 cleavage. Twinning. The optic plane and Z are normal to 010; $X \wedge c$ = 19°. (+) 2V = large, N_g = 1.735 C, 1.749 D, 1.787 F, N_m = 1.669 C, 1.678 D, 1.702 F, N_p = 1.581 C, 1.588 D, 1.603 F, $N_g - N_p$ = 0.161 D. Color yellow with X = colorless, Y = pale yellow, Z = clear yellow.. Made from solution. Stable to about 100° C.

$Fe_2O_3 \cdot 3SO_3 \cdot 6H_2O$ is monoclinic;[42] crystals 010 laths elongated parallel to *c*. The optic plane is 010; $X \wedge c$ = 22° red, 26° blue. (−) 2V = large, N_g = 1.648 C, 1.657 D, 1.681 F, N_m = 1.627 C, 1.635 D, 1.656 F, N_p = 1.598 C, 1.605 D, 1.624 F, $N_g - N_p$ = 0.052 D. Colorless. Made from solution. Stable from 50° to about 160° C.

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[44] Scharizer (*Zeit. Kryst.*, LVI, 1921, p. 353) gives N_g = 1.650, N_m = 1.551 on the natural mineral.

$Fe_2O_3 \cdot 3SO_3 \cdot 7H_2O$ is monoclinic;[42] crystals acicular or 010 plates. The optic plane and Z are normal to 010; $X \wedge c = 20°$. Lamellar twinning. (+) 2V = small, N_g = 1.631 C, 1.640 D, 1.666 F, N_m = 1.579 C, 1.586 D, 1.603 F, N_p = 1.566 C, 1.572 D, 1.585 F, $N_g - N_p$ = 0.078. Colorless to pink. Make from solution below about 80° C.

$Y_2(SO_4)_3 \cdot 8H_2O$ is monoclinic with $a : b : c$ = 3.028 : 1 : 2.009, β = 61° 35′. Crystals equant to columnar by elongation parallel to $11\bar{1}$ and $\bar{1}11$. Twinning on 100. Perfect 001 and distinct 101 cleavages. G. = 2.56. The optic plane is normal to 010; X nearly normal to 001. (+) 2V = 50° 43′, $\rho < v$. N_g = 1.5755, N_m = 1.549, N_p = 1.5433, $N_g - N_p$ = 0.0322. Made from solution.

$Pr_2(SO_4)_3 \cdot 8H_2O$ is monoclinic with $a : b : c$ = 2.986 : 1 : 1.999, β = 62°. Crystals basal tablets or nearly equant with 001, $11\bar{1}$, 100, etc.; perfect 001 and distinct $10\bar{1}$ cleavages. G. = 2.82. Z = *b*; X nearly normal to 001. (+) 2V = 84° 51′ Li, 85° 27′ Na, 84° 52′ Tl, 84° 54′ (490); abnormal variations in 2V between λ = 580 to 600 (an absorption band) shown by : 2V = 84° 50′ (610), 85° 1′ (587), 84° 51′ (584), 84° 37′ (580) N_g = 1.5573 Li, 1.5607 Na, 1.5641 Tl, N_m = 1.5459 Li, 1.5494 Na, 1.5525 Tl, N_p = 1.5366 Li, 1.5399 Na, 1.5430 Tl, $N_g - N_p$ = 0.0208 Na. Color dark green. Made from solution.

$Di_2(SO_4)_3 \cdot 8H_2O$ (Nd dominant) is monoclinic with $a : b : c$ = 2.969 : 1 : 2.006, β = 61° 52′. Crystals 100 or 001 tablets or complex, with perfect 001 cleavage. G. = 2.83. Z = *b*, $X \wedge c$ = 26° ±. (+) 2V = 84° 10′. N_g = 1.5592, N_m = 1.5479, N_p = 1.5392, $N_g - N_p$ = 0.020. Color light red (to green). Made from solution.

$Nd_2(SO_4)_3 \cdot 8H_2O$ is monoclinic with $a : b : c$ = 2.984 : 1 : 1.997, β = 61° 51′. Crystals variable with perfect 001 cleavage. G. = 2.85. Z = *b*. X nearly normal to 001. (+) 2V = 83° 49′ Li, 83° 57′ Na, 83° 46′ Tl. N_g = 1.5583 Li, 1.5621 Na, 1.5652 Tl, N_m = 1.5469 Li, 1.5505 Na, 1.5534 Tl, N_p = 1.5379 Li, 1.5413 Na, 1.5441 Tl, $N_g - N_p$ = 0.0092 Na. Color light red with weak pleochroism with X and Y > Z. Made from solution.

$Sm_2(SO_4)_3 \cdot 8H_2O$ is monoclinic with $a : b : c$ = 3.003 : 1 : 2.002, β = 61° 44′. Crystals 001 tablets, etc., with perfect 001 cleavage. Twinning common on 001. Z = *b*. X nearly normal to 001. (+) 2V = 86° 1′ Li, 85° 56′ Na, 85° 52′ Tl, $\rho > v$ weak. N_g = 1.5594 Li, 1.5629 Na, 1.5663 Tl, N_m = 1.5486 Li, 1.5519 Na, 1.5551 Tl, N_p = 1.5395 Li, 1.5427 Na, 1.5458 Tl, $N_g - N_p$ = 0.0202 Na. Made from solution.

8. HYDROUS SULPHATES, ETC., OF TETRAVALENT BASES

$Th(SO_4)_2 \cdot 8H_2O$ is monoclinic with $a : b : c = 0.754 : 1 : 0.557$, $\beta = 87° 0'$. Crystals prismatic, striated parallel with 001. The optic plane is 010; $Z \wedge c = +65°$. (+) $2V = 76° 20'$, $\rho < v$ weak. $N_m = 1.5168$, $N_g - N_p$ = very weak. Made from solution at about 30° C.

9. ANHYDROUS SULPHATES, ETC., OF DIVALENT AND MONOVALENT BASES

$Na_6Mg(SO_4)_4$ is probably monoclinic without cleavage. H. = 4. G. = 2.69. Soluble in H_2O. Artificial crystals identified by optic measures.[27] (−) $2V = 84° \pm$, $\rho < v$. $N_g = 1.489$, $N_m = 1.488$, $N_p = 1.485$, $N_g - N_p = 0.004$ (nat. cryst.). Colorless. The natural substance, known as *vanthoffite*, is found in salt deposits.

10. HYDROUS SULPHATES, ETC., OF DIVALENT AND MONOVALENT BASES

$Na_2Mg(SO_4)_2 \cdot 2\frac{1}{2}H_2O$ is tetragonal with distinct 001 cleavage. H. = 3.5, G. = 2.37, F. = 1.5. Soluble in H_2O. Artificial crystals identified by optic measures.[27] Uniaxial negative with $N_o = 1.490$, $N_e = 1.471$, $N_o - N_e = 0.019$ (nat. cryst.). Colorless. The natural substance is known as *loewite*.

$K_2Cd(SO_4)_2 \cdot 1\frac{1}{2}H_2O$ is monoclinic with $a : b : c = 0.987 : 1 : 2.025$, $\beta = 75° 18'$. Crystals prismatic with 010 cleavage. The optic plane and Z are normal to 010; $X \wedge c = -69° 15'$. (−) $2V = 63° 33'$ Li, $64° 16'$ Tl, $N_m = 1.509$ Li, 1.511 Tl, $N_g - N_p$ = ? Made from solution at ordinary temperature.

$K_2Mn(SO_4)_2 \cdot 1\frac{1}{2}H_2O$ is monoclinic with $a : b : c = 0.974 : 1 : 1.958$, $\beta = 76° 0'$. Crystals prismatic with distinct 001 cleavage. The optic plane is normal to 010; $X \wedge c = +100°$. (+) $2V = 61° 48'$, $\rho < v$. $N_m = 1.512$ D, $N_g - N_p$ = ? Made from H_2O solution above 55° C.

$Na_2Mg(SO_4)_2 \cdot 4H_2O$ is monoclinic with $a : b : c = 1.349 : 1 : 0.672$, $\beta = 79° 12'$. Crystals nearly equant (with 110, 010, 001, 111, 011, etc.) or 001 tablets with no cleavage. H. = 3. G. = 2.23. Soluble in H_2O. The optic plane is 010; $X \wedge c = -45°$ (red), $-43\frac{1}{2}°$ (blue). (−) $2V = 70° 5'$ (red), $72° 34'$ (blue). Artificial crystals identified by optic measures.[27] $N_g = 1.489$, $N_m = 1.488$, $N_p = 1.486$, $N_g - N_p = 0.003$. Colorless to green or yellow. The natural substance is known as *bloedite* or *astrakanite*.

Picromerite Group

The picromerite group consists of monoclinic sulphates of divalent and monovalent bases with $6H_2O$. It has been studied in great detail by Tutton. The crystal habit of these substances is usually tabular parallel to the base, or short prismatic, but the cæsium salts are domatic parallel to *a* or short prismatic. All the salts have cleavage parallel to 20$\bar{1}$, usually perfect; it is the only distinct cleavage except in certain ammonium salts in one of which, namely $(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$, the 010 cleavage is even better than the 20$\bar{1}$ cleavage. Salts of this group containing copper are blue or greenish blue, those containing nickel or iron are green or bluish green, those containing manganese are rose-red or pink, those containing cobalt are ruby red, and those containing magnesium, zinc, or cadmium are colorless. However, these distinctions are not applicable to very small crystals (or powder) which may appear colorless from nearly any salt. The cæsium-nickel, ammonium-copper and all the thallium salts are optically negative; all the other members of the group are optically positive. The magnesium and copper salts have small optic angles (15°–51°), except the ammonium-copper salt, which has 2V = 68° 31′, the thallium-magnesium salt, which has 2V = 74° 57′, and the thallium-copper salt, which has 2V = 85° 16′. The magnesium salts have notably low refringence (N_m = 1.47–1.48, except for the cæsium-

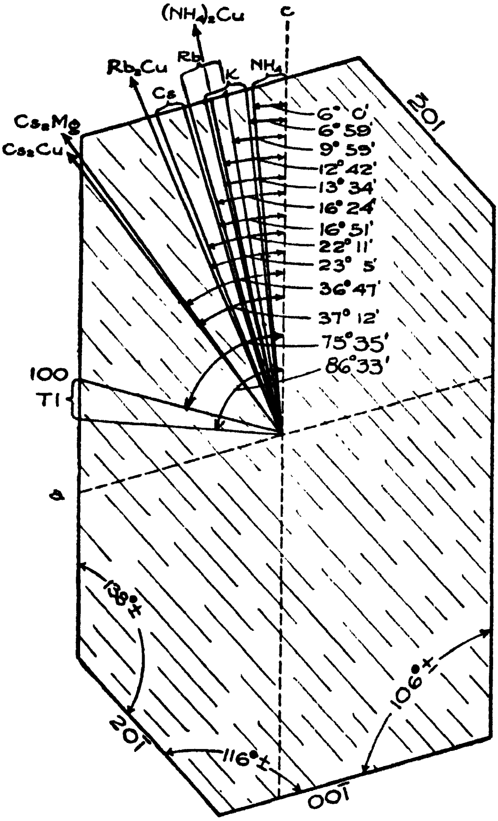

Fig. 241.—Extinction angles (X∧*c*) in the picromerite group.

magnesium salt), and the cæsium salts (except for the cæsium-magnesium and cæsium-manganese salts) have a refringence (N_m = 1.50–1.51) which is high for this group; but the thallium salts have much higher refringence with N_m = 1.59–1.62. The birefringence ranges from 0.006 to 0.024 averaging about 0.01; it is near the higher limit in potassium and thallium salts, and about 0.015 in rubidium salts. The extinction angle between the vibration direction (X) of the fast ray and the vertical axis *c*, measured always in clinopinacoid sections, is +5° to +12°[45] in ammonium salts, except for the ammonium-copper salt in which $X \wedge c = +18\frac{1}{2}°$; it is +9° to +13½° in potassium salts, except for the potassium-copper salt in which it is +18½°; it is +12° to +21° in rubidium salts, except for the rubidium-copper salt, in which $X \wedge c = +26\frac{1}{2}°$; it is +24° to +30° in cæsium salts, except for the cæsium-copper and cæsium-magnesium salts in which $X \wedge c$ = 43° and 47° respectively; it is +73° to +81° in thallium salts. These extinction angles are shown in Fig. 241, which also shows their relations to the $20\bar{1}$ cleavage found in all of these substances.

$K_2Mg(SO_4)_2 \cdot 6H_2O$ is monoclinic[46] with $a : b : c = 0.741 : 1 : 0.499$, $\beta = 75° \, 12'$. Crystals nearly equant as in Fig. 242, short prismatic with perfect $20\bar{1}$ cleavage. H. = 2.5. G. = 2.03. F. = 2. The optic plane is 010; $Z \wedge c = +103° \, 38'$, $X \wedge 20\bar{1}$ cleavage = 27° 50′; (+) 2V = 47° 59′ C, 47° 54′ D, 47° 40′ F, $\rho > v$ very weak. N_g = 1.4731 C, 1.4755 D, 1.4810 F, N_m = 1.4607 C, 1.4629 D, 1.4678 F, N_p = 1.4585 C, 1.4607 D, 1.4658 F, $N_g - N_p$ = 0.0148 D. Colorless. Made from H_2O solution. The natural substance called *picromerite*, is found at Vesuvius and in salt deposits; rare.

$Rb_2Mg(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c = 0.740 : 1 : 0.498$, $\beta = 74° \, 1'$. Crystals thick 001 tablets to short prismatic with distinct $20\bar{1}$ cleavage. G. = 2.38. The optic plane is 010; $Z \wedge c = -68° \, 46'$, $X \wedge 20\bar{1}$ cleavage = 20° 31′. (+) 2V = 49° 2′ C, 48° 46′ D, 48° 10′ F, $\rho > v$ distinct. N_g = 1.4759 C, 1.4779 D, 1.4838 F, N_m = 1.4668 C, 1.4689 D, 1.4743 F, N_p = 1.4650 C, 1.4672 Na, 1.4724 F, $N_g - N_p$ = 0.0107 Na. Colorless. Made from H_2O solution.

$(NH_4)_2Mg(SO_4)_2 \cdot 6H_2O$ is monoclinic[48] with $a : b : c = 0.740 :$

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[45] The positive sign of the extinction angle signifies that it lies in the obtuse angle β between the crystal axes *a* and *c*.

[46] A. E. H. Tutton: *Trans. Chem. Soc.*, LXIX, 1896, p. 344, and LXXXVII, 1905, p. 1160.

[47] A. E. H. Tutton: *Trans. Chem. Soc.*, LXIII, 1893, p. 337, and LXIX, 1896, p. 344.

[48] A. E. H. Tutton: *Trans. Chem. Soc.*, LXXXVII, 1905, p. 1123.

1 : 0.492, $\beta = 72° 54'$. Crystals short prismatic with perfect $20\bar{1}$ and distinct 010 cleavages. H. = 2. G. = 1.72. F. = 1. The optic plane is 010; $Z \wedge c = +94° 58'$, $X \wedge 20\bar{1}$ cleavage = $37° 53'$. (+) $2V = 51° 18'$ C, $51° 11'$ D, $51° 2'$ F, $\rho > v$ very weak. $N_g = 1.4760$ C, 1.4786 D, 1.4842 F, $N_m = 1.4705$ C, 1.4730 D, 1.4786 F, $N_p = 1.4689$ C, 1.4716 D, 1.4771 F, $N_g - N_p = 0.0070$ D. Colorless. Made from H_2O solution. The natural substance, called *boussingaultite*, is found in waters containing borates and about volcanoes; rare.

$Cs_2Mg(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c = 0.728 : 1 : 0.495$, $\beta = 72° 54'$. Crystals short clinodomatic as in Fig. 244 with perfect $20\bar{1}$ cleavage. G. = 2.67. The optic plane is 010 for wavelengths greater than 450 mμ and normal to 010 for shorter wavelengths (blue and violet); $Z \wedge c = -43° 17'$, $X \wedge 20\bar{1}$ cleavage = $4° 47'$. (+) $2V = 18° 0'$ C, $16° 25'$ D, $14° 20'$ Tl, $11° 15'$ F, 0° (450 mμ), $7° 10'$ G. $N_g = 1.4892$ C, 1.4916 D, 1.4970 F, $N_m = 1.4834$ C, 1.4858 D, 1.4912 F, $N_p = 1.4832$ C, 1.4857 D, 1.4912 F, $N_g - N_p = 0.0059$ D. Colorless. Made from H_2O solution.

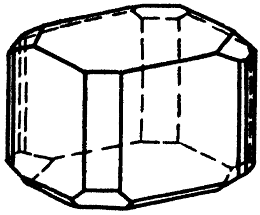

FIG. 242.—A crystal habit of $K_2Mg(SO_4)_2 \cdot 6H_2O$. (After Groth.)

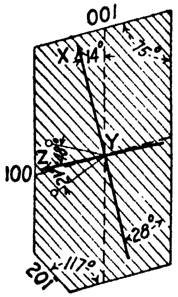

FIG. 243.—Optic orientation of $K_2Mg(SO_4)_2 \cdot 6H_2O$.

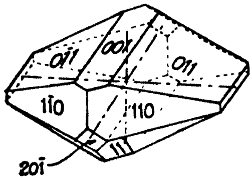

FIG. 244.—A common crystal habit of $Cs_2Mg(SO_4)_2 \cdot 6H_2O$.

$Tl_2Mg(SO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.744 : 1 : 0.500$, $\beta = 73° 30'$. Crystals nearly equant with 110, 011, 010, 001, $\bar{2}01$, $\bar{1}11$, $\bar{1}21$. Distinct $20\bar{1}$ cleavage. G. = 3.57. The optic plane is 010; $Z \wedge c = -9° 4'$, $X \wedge 20\bar{1}$ cleavage = $38° 49'$. (−) $2V = 74° 42'$ C, $74° 57'$ D, $75° 34'$ F. $N_g = 1.5905$ C, 1.5949 D, 1.6063 F, $N_m = 1.5841$ C, 1.5884 D, 1.5993 F, $N_p = 1.5665$ C, 1.5705 D, 1.5808 F, $N_g - N_p = 0.0244$ D. Colorless. Made from H_2O solution.

$K_2Zn(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c = 0.741 : 1 : 0.504$, $\beta = 75° 12'$. Crystals nearly equant, as in Fig. 245, with 001,

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[49] A. E. H. Tutton: *Proc. Roy. Soc.*, CXVIII, 1928, pp. 367–426.

110, etc.; perfect $20\bar{1}$ cleavage. G. = 2.24. The optic plane is 010; $Z \wedge c = +100° 18'$, $X \wedge 20\bar{1}$, cleavage = 30° 52′. (+) 2V = 68° 16′ C, 68° 14′ Na, 68° 9′ F, $\rho > v$ very weak. $N_g = 1.4942$ C, 1.4969 D, 1.5027 F, $N_m = 1.4809$ C, 1.4833 D, 1.4889 F, $N_p = 1.4757$ C, 1.4775 D, 1.4826 F, $N_g - N_p = 0.0194$ D. Colorless. Made from H_2O solution.

$Rb_2Zn(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c = 0.737 : 1 : 0.501$, $\beta = 74° 7'$. Crystals thick 001 tablets (with 110, 001, etc.) with distinct $20\bar{1}$ cleavage. G. = 2.59. The optic plane is 010; $Z \wedge c = -73° 17'$, $X \wedge 20\bar{1}$ cleavage = 24° 50′. (+) 2V = 73° 40′ C, 73° 33′ D, 73° 18′ F, $\rho > v$ very weak. $N_g = 1.4951$ C, 1.4975 D, 1.5033 F, $N_m = 1.4860$ C; 1.4884 D, 1.4938 F, $N_p = 1.4811$ C, 1.4833 D, 1.4886 F, $N_g - N_p = 0.0124$ D. Colorless. Made from H_2O solution.

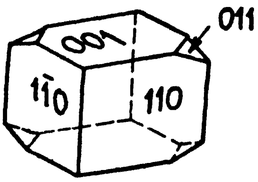

FIG. 245.—A crystal habit of $K_2Zn(SO_4)_2 \cdot 6H_2O$. (After Tutton.)

$(NH_4)_2Zn(SO_4)_2 \cdot 6H_2O$ is monoclinic[48] with $a : b : c = 0.737 : 1 : 0.4997$, $\beta = 73° 8'$. Crystals short prismatic to thick 001 tablets with good $20\bar{1}$ cleavage. G. = 1.93. The optic plane is 010; $Z \wedge c = +97°$, $X \wedge 20\bar{1}$ cleavage = 34° 56′. (+) 2V = 78° 58′ C, 79° 0′ D, 79° 3′ F, $\rho < v$ very weak. $N_g = 1.4967$ C, 1.4994 D, 1.5056 F, $N_m = 1.4904$ C, 1.4930 D, 1.4990 F, $N_p = 1.4862$ C, 1.4888 D, 1.4947 F, $N_g - N_p = 0.0106$ D. Colorless. Made from H_2O solution.

$Cs_2Zn(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c = 0.727 : 1 : 0.496$, $\beta = 72° 59'$. Crystals short, clinodomatic with 011, 001, 110, etc.; distinct $20\bar{1}$ cleavage. G. = 2.87. The optic plane is 010; $Z \wedge c = -59° 44'$, $X \wedge 20\bar{1}$ cleavage = 11° 30′. (+) 2V= 74° 27′ C, 74° 11′ D, 73° 31′ F, $\rho > v$ weak. $N_g = 1.5068$ C, 1.5093 D, 1.5152 F, $N_m = 1.5024$ C, 1.5048 D, 1.5104 F, $N_p = 1.4998$ C, 1.5022 D, 1.5079 F, $N_g - N_p = 0.0071$ D. Colorless. Made from H_2O solution.

$Tl_2Zn(SO_4)_2 \cdot 6H_2O$ is monoclinic[50] with $a : b : c = 0.741 : 1 : 0.501$, $\beta = 73° 44'$. Crystals 001 tablets to short prisms with perfect $20\bar{1}$ cleavage. G. = 3.72. The optic plane is 010; $Z \wedge c = -13° 29'$, $X \wedge 20\bar{1}$ cleavage = 55° 26′. (−) 2V = 69° 12′ C, 69° 24′ D, 69° 55′ F, $\rho < v$ weak. $N_g = 1.6119$ C, 1.6168 D, 1.6281 F, $N_m = 1.6046$ C, 1.6093 D, 1.6203 F, $N_p = 1.5887$ C, 1.5931 D, 1.6033 F, $N_g - N_p = 0.0237$ D. Colorless. Made from H_2O solution.

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[50] A. E. H. Tutton: *Proc. Roy. Soc.*, A, LXXXIII, 1910, p. 211.

$Rb_2Cd(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.735 : 1 : 0.493$, $\beta = 74° 7'$. Crystals thick 001 (or $20\bar{1}$) tablets or short prismatic with perfect $20\bar{1}$ cleavage. G. = 2.70. Effloresces easily. The optic plane is 010; $Z \wedge c = +105° 53'$, $X \wedge 20\bar{1}$ cleavage $= 26° 4'$. (+) $2V = 72° 20'$ C, $72° 26'$ D, $72° 37'$ F, $\rho < v$ very weak. $N_g = 1.4923$ C, 1.4948 D, 1.5007 F, $N_m = 1.4824$ C, 1.4848 D, 1.4905 F, $N_p = 1.4777$ C, 1.4798 D, 1.4856 F, $N_g - N_p = 0.0150$ D. Colorless. Made from H_2O solution.

$(NH_4)_2Cd(SO_4)_2 \cdot 6H_2O$ is monoclinic[52] with $a : b : c = 0.736 : 1 : 0.493$, $\beta = 73° 19'$. Crystals short prismatic or clinodomatic with distinct $20\bar{1}$ cleavage. G. = 2.06. The optic plane is 010; $Z \wedge c = +101° 27'$, $X \wedge 20\bar{1}$ cleavage $= 30° 56'$. (+) $2V = 72° 46'$ C, $72° 51'$ D, $73° 1'$ F, $\rho < v$ very weak. $N_g = 1.4932$ C, 1.4959 D, 1.5019 F, $N_m = 1.4860$ C, 1.4887 D, 1.4947 F, $N_p = 1.4821$ C, 1.4847 D, 1.4907 F, $N_g - N_p = 0.0112$ D. Colorless. Made from H_2O solution.

$Cs_2Cd(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.726 : 1 : 0.491$, $\beta = 72° 49'$. Crystals short clinodomatic to short prismatic with distinct $20\bar{1}$ cleavage. Effloresces slowly. G. = 2.96. The optic plane is 010; $Z \wedge c = -63° 4'$, $X \wedge 20\bar{1}$ cleavage $= 15° 10'$. (+) $2V = 68° 2'$ C, $67° 53'$ D, $67° 28'$ F, $\rho > v$ weak. $N_g = 1.5038$ C, 1.5062 D, 1.5123 F, $N_m = 1.4976$ C, 1.5000 D, 1.5058 F, $N_p = 1.4951$ C, 1.4975 D, 1.5033 F, $N_g - N_p = 0.0087$ D. Colorless. Made from H_2O solution.

$Rb_2Mn(SO_4)_2 \cdot 6H_2O$ is monoclinic[53] with $a : b : c = 0.738 : 1 : 0.495$, $\beta = 74° 3'$. Crystals 001 tablets or short prismatic with perfect $20\bar{1}$ cleavage. Unstable. G. = 2.46. The optic plane is 010; $Z \wedge c = -73° 3'$, $X \wedge 20\bar{1}$ cleavage $= 25° 2'$. (+) $2V = 67° 8'$ C, $67° 5'$ D, $66° 55'$ F, $\rho > v$ very weak. $N_g = 1.4884$ C, 1.4907 D, 1.4965 F, $N_m = 1.4785$ C, 1.4807 D, 1.4860 F, $N_p = 1.4745$ C, 1.4767 D, 1.4821 F, $N_g - N_p = 0.0140$ D. Color rose red. Made from H_2O solution.

$(NH_4)_2Mn(SO_4)_2 \cdot 6H_2O$ is monoclinic[52] with $a : b : c = 0.740 : 1 : 0.493$, $\beta = 73° 9'$. Crystals prismatic with perfect $20\bar{1}$ and distinct 010 cleavages. G. = 1.83. The optic plane is 010; $Z \wedge c = +97° 47'$,

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[51] A. E. H. Tutton: *Trans. Roy. Soc.*, A, 216, 1916, p. 1; *Trans. Chem. Soc.*, LXIII, 1893, p. 337, and LXIX, 1896, p. 344.

[52] A. E. H. Tutton: *Trans. Roy. Soc.*, A, 216, 1916, p. 1. *Trans. Chem. Soc.*, LXXXVII, 1905, p. 1123.

[53] A. E. H. Tutton: *Trans. Roy. Soc.*, A, 216, 1916, p. 1. *Trans. Chem. Soc.*, LXIII, 1893, p. 337.

$X \wedge 20\bar{1}$ cleavage = 34° 56′. (+) 2V = 69° 46′ C, 69° 49′ D, 70° 2′ F, $\rho < v$, very weak. N_g = 1.4887 C, 1.4913 D, 1.4971 F, N_m = 1.4815 C, 1.4840 D, 1.4897 F, N_p = 1.4775 C, 1.4801 D, 1.4858 F, $N_g - N_p$ = 0.0112 D. Color pale pink. Made from H_2O solution.

$Cs_2Mn(SO_4)_2 \cdot 6H_2O$ is monoclinic[53] with $a : b : c$ = 0.727 : 1 : 0.491, β = 72° 53′. Crystals short clinodomatic with perfect $20\bar{1}$ cleavage. G. = 2.74. The optic plane is 010; $Z \wedge c$ = − 64° 33′, $X \wedge 20\bar{1}$ cleavage = 16° 45′. (+) 2V = 60° 7′ C, 59° 57′ D, 59° 28′ F, $\rho > v$ very weak. N_g = 1.4999 C, 1.5025 D, 1.5083 F, N_m = 1.4940 C, 1.4966 D, 1.5022 F, N_p = 1.4922 C, 1.4946 D, 1.5003 F, $N_g - N_p$ = 0.0079 D. Color rose red. Made from H_2O solution.

$Tl_2Mn(SO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c$ = 0.745 : 1 : 0.496, β = 73° 38′. Crystals 001 tablets with large $20\bar{1}$ faces; perfect $20\bar{1}$ cleavage. G. = 3.68. The optic plane is 010; $Z \wedge c$ = − 14° 15′. $X \wedge 20\bar{1}$ cleavage = 33° 21′. (−) 2V = 71° 16′ C, 71° 26′ D, 71° 59′ F. N_g = 1.6047 C, 1.6084 D, 1.6186 F, N_m = 1.5960 C, 1.5996 D, 1.6096 F, N_p = 1.5826 C, 1.5861 D, 1.5959 F, $N_g - N_p$ = 0.0223 D. Color pink. Made from H_2O solution.

$K_2Fe(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c$ = 0.738 : 1 : 0.502, β = 75° 28′. Crystals thick 001 tablets with perfect $20\bar{1}$ cleavage. Effloresces easily. G. = 2.17. The optic plane is 010; $Z \wedge c$ = +101° 57′, $X \wedge 20\bar{1}$ cleavage = 29° 14′. (+) 2V = 67° 2′ C, 67° 7′ D, 67° 19′ F, $\rho < v$ very weak. N_g = 1.4945 C, 1.4969 D, 1.5028 F, N_m = 1.4799 C, 1.4821 D, 1.4877 F, N_p = 1.4735 C, 1.4759 D, 1.4811 F, $N_g - N_p$ = 0.0210 D. Color pale green. Made from H_2O solution.

$Rb_2Fe(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c$ = 0.738 : 1 : 0.5004, β = 74° 16′. Crystals clinodomatic to 001 tablets with distinct $20\bar{1}$ cleavage. G. = 2.52. The optic plane is 010; $Z \wedge c$ = −72° 51′, $X \wedge 20\bar{1}$ cleavage = 24° 27′. (+) 2V = 73° 23′ C, 73° 21′ D, 73° 13′ F, $\rho > v$ very weak, N_g = 1.4953 C, 1.4977 D, 1.5034 F, N_m = 1.4851 C, 1.4874 D, 1.4929 F, N_p = 1.4793 C, 1.4815 D, 1.4870 F, $N_g - N_p$ = 0.0126 D. Color pale green. Made from H_2O solution.

$(NH_4)_2Fe(SO_4)_2 \cdot 6H_2O$ is monoclinic[54] with $a : b : c$ = 0.738 : 1 : 0.496, β = 73° 10′. Crystals thick 001 tablets or short prisms with distinct $20\bar{1}$ cleavage. G. = 1.86. The optic plane is 010; $X \wedge c$ = +98° 42′, $X \wedge 20\bar{1}$ cleavage = 33° 32′. (+) 2V = 76° 18′ C, 76° 25′ D, 76° 33′ F, $\rho > v$ very weak. N_g = 1.4962 C, 1.4989 D, 1.5047 F,

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[54] A. E. H. Tutton: *Proc. Roy. Soc.*, A, LXXXVIII, 1913, p. 361.

$N_m = 1.4890$ C, 1.4915 D, 1.4972 F, $N_p = 1.4844$ C, 1.4870 D, 1.4926 F, $N_g - N_p = 0.0119$ D. Color pale bluish green. Made from H_2O solution.

$Cs_2Fe(SO_4)_2 \cdot 6H_2O$ is monoclinic[47] with $a : b : c = 0.726 : 1 : 0.495$, $\beta = 73° \ 8'$. Crystals short clinodomatic with distinct $20\bar{1}$ cleavage. G. = 2.79. The optic plane is 010; $Z \wedge c = -61° \ 43'$, $X \wedge 20\bar{1}$ cleavage $= 13° \ 27'$. (+) $2V = 75° \ 0'$ C, $74° \ 51'$ D, $74° \ 31'$ F, $\rho > v$ weak. $N_g = 1.5069$ C, 1.5094 D, 1.5153 F, $N_m = 1.5011$ C, 1.5035 D, 1.5093 F, $N_p = 1.4980$ C, 1.5003 D, 1.5061 F, $N_g - N_p = 0.0091$ D. Color pale green. Made from H_2O solution.

$Tl_2Fe(SO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.743 : 1 : 0.4999$, $\beta = 73° \ 44'$. Crystals $20\bar{1}$ tablets with distinct $20\bar{1}$ cleavage. G. = 3.65. The optic plane is 010; $Z \wedge c = -16° \ 15'$, $X \wedge 20\bar{1}$ cleavage $= 31° 42'$. (−) $2V = 68° \ 46'$ C, $69° \ 0'$ D, $69° 59'$ F. $N_g = 1.6117$ C, 1.6162 D, 1.6292 F, $N_m = 1.6048$ C, 1.6093 D, 1.6209 F, $N_p = 1.5886$ C, 1.5929 D, 1.6040 F, $N_g - N_p = 0.0233$ D. Color pale green. Made from H_2O solution.

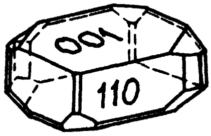

FIG. 246.—A crystal habit of $K_2Cu(SO_4)_2 \cdot 6H_2O$. (After Tutton.)

$K_2Cu(SO_4)_2 \cdot 6H_2O$ is monoclinic[53] with $a : b : c = 0.749 : 1 : 0.509$, $\beta = 75° \ 32'$. Crystals thick 001 tablets, as in Fig. 246, with perfect $20\bar{1}$ cleavage. G. = 2.23. The optic plane is 010; $Z \wedge c = -71° \ 27'$, $X \wedge 20\bar{1}$ cleavage $= 22° \ 36'$. (+) $2V = 46° \ 6'$ C, $46° \ 32'$ D, $47° \ 33'$ F, $\rho < v$ distinct. $N_g = 1.4994$ C, 1.5020 D, 1.5081 F, $N_m = 1.4838$ C, 1.4864 D, 1.4922 F, $N_p = 1.4811$ C, 1.4836 D, 1.4893 F, $N_g - N_p = 0.0184$ D. Color greenish blue. Made from H_2O solution. The natural substance, called ***kyanochroite,*** is found at Vesuvius; rare.

$Rb_2Cu(SO_4)_2 \cdot 6H_2O$ is monoclinic[53] with $a : b : c = 0.749 : 1 : 0.503$, $\beta = 74° \ 42'$. Crystals 001 tablets or short prisms with good $20\bar{1}$ cleavage. G. = 2.57. The optic plane is 010; $Z \wedge c = -63° \ 32'$, $X \wedge 20\bar{1}$ cleavage $= 15° \ 20'$. (+) $2V = 44° \ 29'$ C, $44° \ 42'$ D, $44° \ 57'$ F, $\rho > v$ weak. $N_g = 1.5011$ C, 1.5036 D, 1.5098 F, $N_m = 1.4882$ C, 1.4906 D, 1.4966 F, $N_g = 1.4862$ C, 1.4886 D, 1.4943 F, $N_g - N_p = 0.0150$ D. Color pale greenish blue. Made from H_2O solution.

$(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$ is monoclinic[52] with $a : b : c = 0.746 : 1 : 0.507$, $\beta = 73° \ 51'$. Crystals short prisms or thick 001 tablets with perfect 010 and distinct $20\bar{1}$ cleavages. G. = 1.93. The optic plane is 010; $Z \wedge c = -71^\circ\ 13'$, $X \wedge 20\bar{1}$ cleavage $= 22^\circ\ 49'$. (−) $2V = 68^\circ\ 57'$ C, $68^\circ\ 31'$ D, $66^\circ\ 55'$ F, $\rho > v$ distinct. $N_g = 1.5025$ C; 1.5054 D, 1.5116 F, $N_m = 1.4977$ C, 1.5007 D, 1.5067 F, $N_p = 1.4883$ C, 1.4910 D, 1.4971 F, $N_g - N_p = 0.0144$ D. Color pale blue. Made from H_2O solution.

$Cs_2Cu(SO_4)_2 \cdot 6H_2O$ is monoclinic[53] with $a : b : c = 0.743 : 1 : 0.495$, $\beta = 73^\circ\ 50'$. Crystals clinodomatic to short prismatic with distinct $20\bar{1}$ cleavage. G. = 2.86. The optic plane is 010; $Z \wedge c = -47^\circ\ 3'$, $X \wedge 20\bar{1}$ cleavage $= 0^\circ\ 37'$. (+) $2V = 43^\circ\ 9'$ C, $43^\circ\ 24'$ D, $44^\circ\ 3'$ F, $\rho < v$ weak. $N_g = 1.5126$ C, 1.5153 D, 1.5216 F, $N_m = 1.5036$ C, 1.5061 D, 1.5123 F, $N_g = 1.5021$ C, 1.5048 D, 1.5108 F, $N_g - N_p = 0.0105$ D. Color pale greenish blue. Made from H_2O solution.

$Tl_2Cu(SO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.750 : 1 : 0.503$, $\beta = 74^\circ\ 27'$. Crystals equant to flattened parallel with 001 with 110, 011 and $20\bar{1}$ prominent; distinct $20\bar{1}$ cleavage. G. = 3.73. The optic plane is 010; $Z \wedge c = -17^\circ\ 20'$, $X \wedge 20\bar{1}$ cleavage $= 30^\circ\ 49'$. (−) $2V = 85^\circ\ 21'$ C, $85^\circ\ 16'$ D, $85^\circ\ 2'$ F. $N_g = 1.6144$ C, 1.6190 D, 1.6318 F, $N_m = 1.6050$ C, 1.6096 D, 1.6222 F, $N_p = 1.5950$ C, 1.5996 D, 1.6120 F, $N_g - N_p = 0.0194$ D. Color bright blue. Made from H_2O solution.

$K_2Co(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.740 : 1 : 0.504$, $\beta = 75^\circ\ 5'$. Crystals short prismatic to 001 tablets with 110 and 001 dominant as in Fig. 247, distinct $20\bar{1}$ cleavage. G. = 2.22. The optic plane is 010; $Z \wedge c = +100^\circ\ 5'$, $X \wedge 20\bar{1}$ cleavage $= 31^\circ\ 12'$. (+) $2V = 68^\circ\ 39'$ C, $68^\circ\ 41'$ D, $68^\circ\ 48'$ F, $\rho < v$ very weak. $N_g = 1.4977$ C, 1.5004 D, 1.5059 F, $N_m = 1.4842$ C, 1.4865 D, 1.4919 F, $N_p = 1.4784$ C, 1.4807 D, 1.4861 F, $N_g - N_p = 0.0197$ D. Color ruby red with X = violet red, Y = yellow, Z = yellowish pink. Made from H_2O solution.

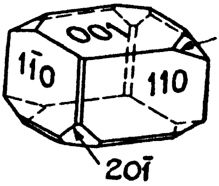

FIG. 247.—A crystal habit of $K_2Co(SO_4)_2 \cdot 6H_2O$. (After Tutton.)

$Rb_2Co(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.739 : 1 : 0.501$, $\beta = 73^\circ\ 59'$. Crystals short prismatic to thick 001 tablets with perfect $20\bar{1}$ cleavage. G. = 2.56. The optic plane is 010; $Z \wedge c = +106^\circ\ 1'$, $X \wedge 20\bar{1}$ cleavage $= 25^\circ\ 36'$. (+) $2V = 75^\circ\ 14'$ C, $75^\circ\ 11'$ D, $75^\circ\ 3'$ F, $\rho > v$ very weak. $N_g = 1.4989$ C, 1.5014 D, 1.5068 F, $N_m = 1.4893$ C, 1.4916 D, 1.4968 F, $N_g = 1.4837$ C, 1.4859 D, 1.4910 F, $N_g - N_p = 0.0155$ D. Color ruby red. Made from H_2O solution.

$(NH_4)_2Co(SO_4)_2 \cdot 6H_2O$ is monoclinic[52] with $a : b : c = 0.737 : 1 : 0.498$, $\beta = 72° 58'$. Crystals short prismatic or 001 tablets with distinct $20\bar{1}$ cleavage. G. = 1.90. The optic plane is 010; $Z \wedge c = +96° 19'$, $X \wedge 20\bar{1}$ cleavage = $35° 57'$. (+) $2V = 82° 2'$ C, $82° 9'$ D $82° 27'$ F, $\rho < v$ very weak. $N_g = 1.5006$ C, 1.5032 D, 1.5094 F $N_m = 1.4927$ C, 1.4953 D, 1.5014 F, $N_p = 1.4876$ C, 1.4902 D, 1.4964 F, $N_g - N_p = 0.0130$ D. Color ruby red. Made from H_2O solution.

$Cs_2Co(SO_4)_2 \cdot 6H_2O$ is monoclinic with[51] $a : b : c = 0.727 : 1 : 0.497$, $\beta = 72° 52'$. Crystals clinodomatic with distinct $20\bar{1}$ cleavage. G. = 2.84. The optic plane is 010; $Z \wedge c = -63° 52'$, $X < 20\bar{1}$ cleavage = $15° 36'$. (+) $2V = 81° 40'$ C, $81° 34'$ D, $81° 22'$ F. $N_g = 1.5106$ C, 1.5132 D, 1.5187 F, $N_m = 1.5061$ C, 1.5085 D, 1.5142 F, $N_p = 1.5032$ C, 1.5057 D, 1.5112 F, $N_g - N_p = 0.0075$ D. Color brownish red. Made from H_2O solution.

$Tl_2Co(SO_4)_2 \cdot 6H_2O$[55] is monoclinic with $a : b : c = 0.741 : 1 : 0.4995$, $\beta = 73° 35'$. Crystals short clinodomatic to 001 tablets with distinct $20\bar{1}$ and poor 010 cleavages. G. = 3.78. The optic plane is 010; $Z \wedge c = -15° 40'$, $X \wedge 20\bar{1}$ cleavage = $32° 22'$. (−) $2V = 66° 7'$ C, $66° 39'$ D, $67° 8'$ Tl, $\rho < v$ distinct with weak inclined dispersion. $N_g = 1.6188$ C, 1.6238 D, 1.6359 F, $N_m = 1.6128$ C, 1.6176 D, 1.6293 F, $N_p = 1.5965$ C, 1.6009 D, 1.6121 F, $N_g - N_p = 0.0229$ D. Color ruby red. Difficultly prepared from solution.

$K_2Ni(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.738 : 1 : 0.502$, $\beta = 75° 0'$. Crystals short prismatic to thick 001 tablets with perfect $20\bar{1}$ cleavage. G. = 2.24. The optic plane is 010; $Z \wedge c + 98° 42'$, $X \wedge 20\bar{1}$ cleavage = $32° 34'$. (+) $2V = 75° 19'$ C, $75° 16'$ D, $75° 9'$ F, $\rho > v$ very weak. $N_g = 1.5026$ C, 1.5051 D, 1.5109 F, $N_m = 1.4893$ C, 1.4916 D, 1.4972 F, $N_p = 1.4813$ C, 1.4836 D, 1.4889 F, $N_g - N_p = 0.0215$ D. Color bright green. Made from H_2O solution.

$Rb_2Ni(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.735 : 1 : 0.502$, $\beta = 73° 57'$. Crystals short prismatic to 001 tablets with $20\bar{1}$ cleavage. G. = 2.59. The optic plane is 010; $Z \wedge c = +102° 38'$, $X \wedge 20\bar{1}$ cleavage = $28° 49'$. (+) $2V = 82° 4'$ C, $82° 0'$ D, $81° 48'$ F, $\rho > v$ very weak, $N_g = 1.5027$ C, 1.5052 D, 1.5110 F, $N_m = 1.4937$ C, 1.4961 D, 1.5017 F, $N_p = 1.4872$ C, 1.4895 D, 1.4949 F, $N_g - N_p = 0.0157$ D. Color deep green. Made from H_2O solution.

$(NH_4)_2Ni(SO_4)_2 \cdot 6H_2O$ is monoclinic[52] with $a : b : c = 0.737 : 1 : 0.500$, $\beta = 73° 3'$. Crystals short prisms or 001 tablets with distinct $20\bar{1}$ and 010 cleavages. G. = 1.92. The optic plane is 010; $Z \wedge c = +95° 12'$, $X \wedge 20\bar{1}$ cleavage = 36° 40′. (+) 2V = 86° 33′, $\rho < v$ very weak. $N_g = 1.5051$ C, 1.5081 D, 1.5142 F, $N_m = 1.4980$ C, 1.5007 D, 1.5069 F, $N_p = 1.4921$ C, 1.4949 D, 1.5007 F, $N_g - N_p = 0.0132$ D. Color deep bluish green. Made from H_2O solution.

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[55] A. E. H. Tutton; *Proc. Roy. Soc.*, A, CVIII, 1925, p. 240.

$Cs_2Ni(SO_4)_2 \cdot 6H_2O$ is monoclinic[51] with $a : b : c = 0.727 : 1 : 0.498$, $\beta = 72° 58'$. Crystals clinodomatic with distinct $20\bar{1}$ cleavage. G. = 2.87. The optic plane is 010; $Z \wedge c = -65° 53'$. $X \wedge 20\bar{1}$ cleavage = 17° 27′. (−) 2V = 87° 17′ C, 87° 21′ D, 87° 40° F, $\rho < v$ very weak. $N_g = 1.5137$ C, 1.5162 D, 1.5221 F, $N_m = 1.5104$ C, 1.5129 D, 1.5187 F, $N_p = 1.5065$ C, 1.5087 D, 1.5146 F, $N_g - N_p = 0.0075$ D. Color bright green. Made from H_2O solution.

$Tl_2Ni(SO_4)_2 \cdot 6H_2O$ is monoclinic[55] with $a : b : c = 0.740 : 1 : 0.4997$, $\beta = 73° 37'$. Crystals short clinodomatic with 001, 110, etc. Distinct $20\bar{1}$ cleavage. G. = 3.77. The optic plane is 010; $Z \wedge c = -14° 40'$, $X \wedge 20\bar{1}$ cleavage = 33° 23′. (−) 2V = 60° 58′ C, 61° 37′ D, 63° 11′ F, $\rho < v$ strong. $N_g = 1.6190$ C, 1.6224 D, 1.6324 F, $N_m = 1.6150$ C, 1.6183 D, 1.6280 F, $N_p = 1.5990$ C, 1.6024 D, 1.6115 F, $N_g - N_p = 0.0200$ D. Merwin[56] gives $N_g = 1.6252$, $N_m = 1.6184$, $N_p = 1.6025$, $N_g - N_p = 0.0227$ D. Color green. Difficultly prepared from solution.

Tutton's Selenate Group

The group of monoclinic selenates of divalent and monovalent bases with $6H_2O$ has been studied in great detail by Tutton. These substances have a crystal habit which is usually tabular parallel to the base, or short prismatic, but the cæsium salts are domatic parallel to *a*, or short prismatic. All these salts have cleavage parallel to $20\bar{1}$, usually perfect; it is the only distinct cleavage except in certain ammonium salts which have 010 cleavage. Salts of this group containing copper are blue, those containing nickel are decided green, those containing iron are pale bluish or yellowish green, those containing manganese are pink, those containing cobalt are deep red and those containing magnesium, zinc, or cadmium are colorless. However, these color distinctions are not applicable to very small crystals (or powder) which may appear colorless almost regardless of the composition. The cæsium-nickel, potassium-copper, rubidium-copper, ammonium-copper and all the thallium salts are optically negative; all the other

[56] *Int. Crit. Tab.*, VII, 1930, p. 31.

members of the group are optically positive. The magnesium salts (except the thallium-magnesium salt with $2V = 77\frac{1}{2}°$) have smaller optic angles (18°–55°) than other members of the group. The nickel, cobalt, zinc, and iron salts (except those containing potassium or thallium) have large optic angles (75°–87°). The magnesium salts (except the thallium-magnesium salt with $N_m = 1.63$) have the lowest refringence in the group ($N_m = 1.50$–1.52) and the thallium salts have the highest refringence with $N_m = 1.63$–1.65; the potassium and thallium salts have the strongest birefringence, namely, 0.021–0.0324 (except the potassium-magnesium salt with $N_g - N_p = 0.017$, the thallium-magnesium salt with $N_g - N_p = 0.0154$, the thallium-nickel salt with $N_g - N_p = 0.0182$, and the thallium-cobalt salt with $N_g - N_p = 0.0148$). The extinction angle between the vibration direction (X) of the fast ray and the vertical axis (c), measured in clinopinacoid sections, is +0° 13′ to +6° 0′ in ammonium salts except in the ammonium-copper salt, which has $X \wedge c = +12°\ 42'$. The extinction angle is +6° 59′ to +13° 34′ in potassium salts; it is +9° 59′ to +16° 24′ in rubidium salts, except for the rubidium-copper salt in which $X \wedge c = +23°\ 5'$; it is +16° 51′ to +22′ 11′ in the cæsium salts except for the cæsium-magnesium and cæsium-copper salts in which $X \wedge c = 36°\ 47'$ and 37° 12′ respectively; it is 75° 35′ to 86° 33′ in thallium salts. These extinction angles are shown in Fig. 248 which also shows their relations to the 20$\bar{1}$ cleavage found in all these salts.

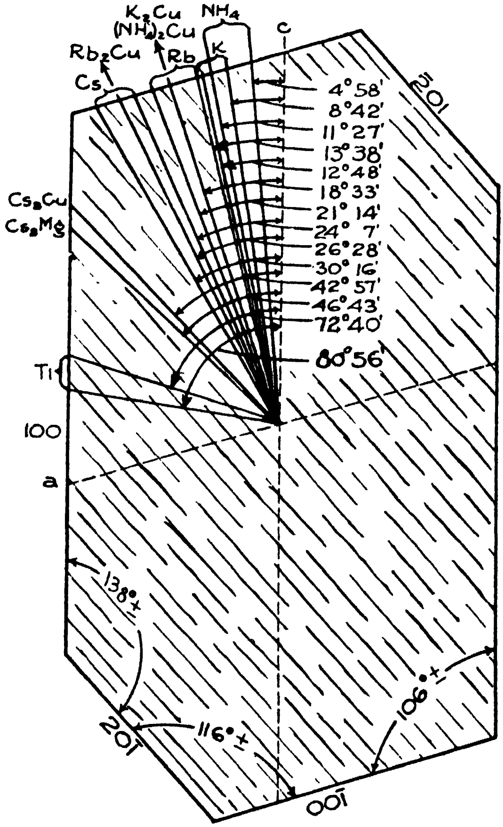

FIG. 248.—Extinction angles ($X \wedge c$) in Tutton's selenate group.

$K_2Mg(SeO_4)_2 \cdot 6H_2O$ is monoclinic[57] with $a : b : c = 0.749 : 1 : 0.503$, $\beta = 75^\circ 42'$. Crystals short prismatic to 001 tablets with distinct $20\bar{1}$ cleavage. G. = 2.36. The optic plane is 010; $Z \wedge c = +101^\circ 18'$, $X \wedge 20\bar{1}$ cleavage $= 30^\circ 7'$. (+) $2V = 39^\circ 42'$ C, $39^\circ 38'$ D, $39^\circ 25'$ F, $\rho > v$ very weak. $N_g = 1.5108$ C, 1.5139 D, 1.5210 F, $N_m = 1.4963$ C, 1.4991 D, 1.5058 F, $N_p = 1.4941$ C, 1.4969 D, 1.5035 F, $N_g - N_p = 0.0170$ D. Colorless. Made from H_2O solution.

$Rb_2Mg(SeO_4)_2 \cdot 6H_2O$ is monoclinic[57] with $a : b : c = 0.742 : 1 : 0.501$, $\beta = 74^\circ 46'$. Crystals thick 001 tablets to short prisms with distinct $20\bar{1}$ cleavage. G. = 2.68. The optic plane is 010; $Z \wedge c = -73^\circ 36'$, $X \wedge 20\bar{1}$ cleavage $= 25^\circ 13'$. (+) $2V = 47^\circ 24'$ C, $47^\circ 3'$ D, $46^\circ 6'$ F, $\rho > v$ weak. $N_g = 1.5105$ C, 1.5135 D, 1.5205 F, $N_m = 1.5002$ C, 1.5031 D, 1.5098 F, $N_p = 1.4983$ C, 1.5011 D, 1.5077 F, $N_g - N_p = 0.0124$ D. Colorless. Made from H_2O solution.

$(NH_4)_2Mg(SeO_4)_2 \cdot 6H_2O$ is monoclinic[48] with $a : b : c = 0.742 : 1 : 0.497$, $\beta = 73^\circ 33'$. Crystals short prisms or thick 001 tablets with perfect $20\bar{1}$ cleavage. G. = 2.06. The optic plane is 010; $Z \wedge c = +90^\circ 13'$; $X \wedge 20\bar{1}$ cleavage $= 31^\circ 59'$. (+) $2V = 54^\circ 55'$ C, $54^\circ 47'$ D, $54^\circ 4'$ F, $\rho > v$ very weak. $N_g = 1.5136$ C, 1.5169 D, 1.5242 F, $N_m = 1.5060$ C, 1.5093 D, 1.5166 F, $N_p = 1.5038$ C, 1.5070 D, 1.5144 F, $N_g - N_p = 0.0099$ Na. Colorless. Made from H_2O solution.

$Cs_2Mg(SeO_4)_2 \cdot 6H_2O$ is monoclinic[57] with $a : b : c = 0.731 : 1 : 0.496$, $\beta = 73^\circ 43'$. Crystals clinodomatic, with distinct $20\bar{1}$ cleavage. G. = 2.94. The optic plane is 010 for wave-lengths greater than 466 mμ and normal to 010 for shorter wave-lengths (blue). $Z \wedge c = -53^\circ 13'$, $X \wedge 20\bar{1}$ cleavage $= 4^\circ 59'$. (+) $2V = 20^\circ 34'$ C, $18^\circ 35'$ D, $10^\circ 30'$ F, 0° (466 mμ), $12^\circ 49'$ G. At 78° C. it is uniaxial for Na light. $N_g = 1.5206$ C, 1.5236 D, 1.5308 F, $N_m = 1.5150$ C, 1.5179 D, 1.5248 F, $N_p = 1.5148$ C, 1.5178 D, 1.5248 F, $N_g - N_p = 0.0058$ D. Colorless. Made from H_2O solution.

$Tl_2Mg(SeO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.749 : 1 : 0.499$, $\beta = 74^\circ 24'$. Crystals 001 tablets with 110, 011, etc. Distinct $20\bar{1}$ cleavage. G. = 3.72. The optic plane is 010; $Z \wedge c = -4^\circ 27'$, $X \wedge 20\bar{1}$ cleavage $= 43^\circ 27'$. (−) $2V = 77^\circ 20'$ C, $77^\circ 33'$ D, $78^\circ 10'$ F. $N_g = 1.6364$ C, 1.6404 D, 1.6521 F, $N_m = 1.6297$ C, 1.6337 D, 1.6452 F, $N_p = 1.6210$ C, 1.6250 D, 1.6363 F, $N_g - N_p = 0.0154$ D. Colorless. Made from H_2O solution with magnesium selenate in excess.

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[57] A. E. H. Tutton: *Trans. Roy. Soc.*, A, 197, 1901, p. 255.

$K_2Zn(SeO_4)_2\cdot 6H_2O$ is monoclinic[58] with $a : b : c = 0.746 : 1 : 0.507$, $\beta = 75° 48'$. Crystals short prismatic to thick 001 tablets with distinct 20$\bar{1}$ cleavage. G. = 2.56. The optic plane is 010; $Z \wedge c = +99° 9'$, $X \wedge 20\bar{1}$ cleavage $= 31° 51'$. (+) $2V = 66° 13'$ C, $66° 15'$ D, $66° 20'$ F, $\rho < v$ very weak. $N_g = 1.5302$ C, 1.5335 D, 1.5410 F, $N_m = 1.5151$ C, 1.5181 D, 1.5252 F, $N_p = 1.5092$ C, 1.5121 D, 1.5189 F, $N_g - N_p = 0.0214$ D. Colorless. Made from H_2O solution.

$Rb_2Zn(SeO_4)_2\cdot 6H_2O$ is monoclinic[58] with $a : b : c = 0.743 : 1 : 0.502$, $\beta = 74° 44'$. Crystals thick 001 tablets or short prisms with perfect 20$\bar{1}$ cleavage. G. = 2.87. The optic plane is 010; $Z \wedge c = +103° 13'$, $X \wedge 20\bar{1}$ cleavage $= 28° 21'$. (+) $2V = 75° 14'$ C, $75° 8'$ D, $74° 55'$ F, $\rho > v$ very weak. $N_g = 1.5299$ C, 1.5331 D, 1.5405 F, $N_m = 1.5193$ C, 1.5222 D, 1.5293 F, $N_p = 1.5134$ C, 1.5162 D, 1.5233 F, $N_g - N_p = 0.0169$ D. Colorless. Made from H_2O solution.

$(NH_4)_2Zn(SeO_4)_2\cdot 6H_2O$ is monoclinic[48] with $a : b : c = 0.741 : 1 : 0.504$, $\beta = 73° 46'$. Crystals short prisms or thick 001 tablets with perfect 20$\bar{1}$ cleavage. G. = 2.26. The optic plane is 010; $Z \wedge c = +93° 24'$, $X \wedge 20\bar{1}$ cleavage $= 38° 14'$. (+) $2V = 82° 5'$ C, $82° 7'$ D, $82° 10'$ F, $\rho < v$ very weak. $N_g = 1.5349$ C, 1.5385 D, 1.5463 F, $N_m = 1.5265$ C, 1.5300 D, 1.5378 F, $N_p = 1.5206$ C, 1.5240 D, 1.5316 F, $N_g - N_p = 0.0145$ D. Colorless. Made from H_2O solution.

$Cs_2Zn(SeO_4)_2\cdot 6H_2O$ is monoclinic[58] with $a : b : c = 0.731 : 1 : 0.497$, $\beta = 73° 49'$. Crystals clinodomatic with perfect 20$\bar{1}$ cleavage G. = 3.12. The optic plane is 010; $Z \wedge c = -68° 3'$, $X \wedge 20\bar{1}$ cleavage $= 19° 48'$. (+) $2V = 83° 30'$ C, $83° 6'$ D, $82° 14'$ F, $\rho > v$ weak. $N_g = 1.5380$ C, 1.5412 D, 1.5488 F, $N_m = 1.5331$ C, 1.5362 D, 1.5435 F, $N_p = 1.5295$ C, 1.5326 D, 1.5399 F, $N_g - N_p = 0.0086$ D. Colorless. Made from H_2O solution.

$Tl_2Zn(SeO_4)_2\cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.748 : 1 : 0.502$, $\beta = 74° 6'$. Crystals 001 tablets bounded by 110, with small 100 and 010 faces, or by 20$\bar{1}$, 110 and 011. Distinct 20$\bar{1}$ cleavage. G. = 3.96. The optic plane is 010; $Z \wedge c = -6° 46'$, $X \wedge 20\bar{1}$ cleavage $= 41° 14'$. (−) $2V = 68° 15'$ C, $68° 34'$ D, $69° 30'$ F. $N_g = 1.6555$ C, 1.6615 D, 1.6793 F, $N_m = 1.6481$ C, 1.6539 D, 1.6706 F, $N_p = 1.6358$ C, 1.6414 D, 1.6576 F, $N_g - N_p = 0.0201$ D. Colorless. Made from H_2O solution with zinc selenate in excess.

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[58] A. E. H. Tutton: *Proc. Roy. Soc.*, A, LXVII, 1900, p. 58; *Zeit. Kryst.*, XXXIII, 1900, p. 1.

$(NH_4)_2Cd(SeO_4)_2 \cdot 6H_2O$ is monoclinic [59] with $a : b : c = 0.742 : 1 : 0.503$, $\beta = 75° 59'$. Crystals 001 or $20\bar{1}$ tablets or varied, with distinct $20\bar{1}$ cleavage. G. = 2.45. The optic plane is 010; $Z \wedge c = +96° 0'$, $X \wedge 20\bar{1}$ cleavage = $35° 44'$. (+) $2V = 76° 11'$ C, $76° 31'$ D, $77° 13'$ F, $\rho < v$ weak. $N_g = 1.5317$ C, 1.5352 D, 1.5427 F, $N_m = 1.5227$ C, 1.5260 D, 1.5338 F, $N_p = 1.5172$ C, 1.5206 D, 1.5283 F, $N_g - N_p = 0.0146$ D. Colorless. Made from H_2O solution at about 0° C.

$Rb_2Mn(SeO_4)_2 \cdot 6H_2O$ is monoclinic [60] with $a : b : c = 0.742 : 1 : 0.501$, $\beta = 74° 51'$. Crystals 001 tablets or short prisms with good $20\bar{1}$ cleavage. G. = 2.76. The optic plane is 010; $Z \wedge c = +103° 7'$, $X \wedge 20\bar{1}$ cleavage = $28° 27'$. (+) $2V = 66° 5'$ C, $66° 2'$ D, $65° 52'$ F, $\rho < v$ very weak. $N_g = 1.5226$ C, 1.5258 D, 1.5332 F, $N_m = 1.5110$ C, 1.5140 D, 1.5210 F, $N_p = 1.5064$ C, 1.5094 D, 1.5163 F, $N_g - N_p = 0.0164$ D. Color pale pink. Made from H_2O solution.

$(NH_4)_2Mn(SeO_4)_2 \cdot 6H_2O$ is monoclinic [60] with $a : b : c = 0.743 : 1 : 0.499$, $\beta = 73° 44'$. Crystals 001 tablets or prisms, varied, with perfect 010 and distinct $20\bar{1}$ cleavages. G. = 2.16. The optic plane is 010; $Z \wedge c = +93° 22'$, $X \wedge 20\bar{1}$ cleavage $= 38° 42'$. (+) $2V = 70° 18'$ C, $70° 23'$ D, $70° 34'$ F, $\rho < v$ very weak. $N_g = 1.5255$ C, 1.5288 D, 1.5364 F, $N_m = 1.5169$ C, 1.5202 D, 1.5276 F, $N_p = 1.5128$ C, 1.5160 D, 1.5235 F, $N_g - N_p = 0.0128$ D. Color pink. Made from H_2O solution.

$Cs_2Mn(SeO_4)_2 \cdot 6H_2O$ is monoclinic [60] with $a : b : c = 0.732 : 1 : 0.496$, $\beta = 73° 38'$. Crystals clinodomatic to short prismatic with perfect $20\bar{1}$ cleavage. G. = 3.01. The optic plane is 010; $Z \wedge c = -67° 49'$, $X \wedge 20\bar{1}$ cleavage = $19° 36'$. (+) $2V = 69° 1'$ C, $68° 49'$ D, $68° 5'$ F, $\rho > v$ weak, $N_g = 1.5306$ C, 1.5338 D, 1.5415 F, $N_m = 1.5248$ C, 1.5279 D, 1.5350 F, $N_p = 1.5220$ C, 1.5250 D, 1.5323 F, $N_g - N_p = 0.0088$ D. Color pink. Made from H_2O solution.

$Tl_2Mn(SeO_4)_2 \cdot 6H_2O$ is monoclinic [49] with $a : b : c = 0.746 : 1 : 0.499$, $\beta = 74° 31'$. Crystals 001 tablets bounded by 110. Distinct $20\bar{1}$ cleavage. G. = 3.83. The optic plane is 010; $Z \wedge c = -8° 21'$, $X \wedge 20\bar{1}$ cleavage = $39° 43'$. (−) $2V = 72° 4'$ C, $72° 27'$ D, $73° 32'$ F. $N_g = 1.6470$ C, 1.6531 D, 1.6685 F, $N_m = 1.6370$ C, 1.6429 D, 1.6579 F, $N_p = 1.6219$ C, 1.6276 D, 1.6422 F, $N_g - N_p = 0.0255$ D. Color pink. Made from H_2O solution with manganese selenate in excess.

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[59] A. E. H. Tutton: *Proc. Roy. Soc.*, A, 101, 1922, p. 245.

[60] A. E. H. Tutton: *Proc. Roy. Soc.*, A, 101, 1922, p. 225.

$K_2Fe(SeO_4)_2 \cdot 6H_2O$ is monoclinic[61] with $a : b : c = 0.749 : 1 : 0.504$, $\beta = 76° 10'$. Crystals thick 001 tablets to short prismatic with $20\bar{1}$ cleavage. G. = 2.49. The optic plane is 010; $Z \wedge c = +100° 27'$, $X \wedge 20\bar{1}$ cleavage = 30° 45'. (+) 2V = 64° 12' C, 64° 18' D, 64° 36' F, $\rho < v$ very weak. $N_g = 1.5311$ C, 1.5345 D, 1.5421 F, $N_m = 1.5149$ C, 1.5182 D, 1.5253 F, $N_p = 1.5064$ C, 1.5095 D, 1.5164 F, $N_g - N_p = 0.0255$ D. Color pale green. Made from H_2O solution at 0° C. Dehydrates quickly at ordinary temperature.

$Rb_2Fe(SeO_4)_2 \cdot 6H_2O$ is monoclinic[61] with $a : b : c = 0.742 : 1 : 0.500$, $\beta = 75° 3'$. Crystals clinodomatic to 010 tablets with distinct $20\bar{1}$ cleavage. G. = 2.80. The optic plane is 001; $Z \wedge c = +103° 37'$, $X \wedge 20\bar{1}$ cleavage = 27° 56'. (+) 2V = 73° 34' C, 73° 32' D, 73° 26' F, $\rho > v$ very weak. $N_g = 1.5295$ C, 1.5328 D, 1.5404 F, $N_m = 1.5170$ C, 1.5200 D, 1.5272 F, $N_p = 1.5104$ C, 1.5133 D, 1.5202 F, $N_g - N_p = 0.0191$ D. Color pale bluish green. Made from H_2O solution at about 0° C.

$(NH_4)_2Fe(SeO_4)_2 \cdot 6H_2O$ is monoclinic[61] with $a : b : c = 0.743 : 1 : 0.502$, $\beta = 73° 51'$. Crystals thick 001 tablets to short prismatic with good $20\bar{1}$ cleavage. G. = 2.19. The optic plane is 010; $Z \wedge c = +95° 24'$, $X \wedge 20\bar{1}$ cleavage = 36° 28'. (+) 2V = 77° 37' C, 77° 44' D, 77° 54' F, $\rho < v$ very weak. $N_g = 1.5348$ C, 1.5381 D, 1.5457 F, $N_m = 1.5246$ C, 1.5280 D, 1.5354 F, $N_p = 1.5182$ C, 1.5216 D, 1.5291 F, $N_g - N_p = 0.0165$ D. Color very pale yellowish green. Made from H_2O solution at 0° C.

$Cs_2Fe(SeO_4)_2 \cdot 6H_2O$ is monoclinic[61] with $a : b : c = 0.731 : 1 : 0.498$, $\beta = 73° 58'$. Crystals clinodomatic with perfect $20\bar{1}$ cleavage. G. = 3.05. The optic plane is 010; $Z \wedge c = 68° 56'$, $X \wedge 20\bar{1}$ cleavage = 20° 27'. (+) 2V = 82° 56' C, 82° 47' D, 82° 20' F, $\rho > v$ very weak. $N_g = 1.5384$ C, 1.5414 D, 1.5491 F, $N_m = 1.5322$ C, 1.5352 D, 1.5425 F, $N_p = 1.5274$ C, 1.5306 D, 1.5379 F, $N_g - N_p = 0.0108$ D. Color very pale bluish green. Made from H_2O solution at 0° C.

$Tl_2Fe(SeO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.745 : 1 : 0.501$, $\beta = 74° 33'$. Crystals thick 001 tablets with 110, 011, 001, 010, 100, $20\bar{1}$, $\bar{1}11$, and $\bar{1}21$. Distinct $20\bar{1}$ cleavage. G. = 3.94. The optic plane is 010: $Z \wedge c = -9° 9'$, $X \wedge 20\bar{1}$ cleavage = 39° 2'. (−) 2V = 69° 5' C, 69° 36' D, 70° 45' F. $N_g = 1.6533$ C, 1.6589 D, 1.6743 F, $N_m = 1.6459$ C, 1.6514 D, 1.6662 F, $N_p = 1.6297$ C, 1.6352 D, 1.6496 F, $N_g - N_p = 0.0237$ D. Color of fresh crystals very pale green, slowly becoming yellowish green. Made from H_2O solution with iron selenate in excess.

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[61] A. E. H. Tutton: *Trans. Roy. Soc.*, A, 218, 1919, p. 395; *Proc. Roy. Soc.*, A, 94, 1918, p. 352.

$K_2Cu(SeO_4)_2 \cdot 6H_2O$ is monoclinic[62] with $a : b : c = 0.751 : 1 : 0.514$, $\beta = 76° \ 35'$. Crystals short prismatic or 001 tablets with perfect $20\bar{1}$ and distinct 010 cleavages. G. = 2.54. The optic plane is 010; $Z \wedge c = -76° \ 26'$, $X \wedge 20\bar{1}$ cleavage = $26° \ 56'$. $(-)$ $2V = 88° 46'$ C, $88° \ 27'$ D, $87° \ 36'$ F, $\rho > v$ weak. $N_g = 1.5317$ C, 1.5349 D, 1.5428 F, $N_m = 1.5195$ C, 1.5228 D, 1.5308 F, $N_p = 1.5068$ C, 1.5101 D, 1.5171 F, $N_g - N_p = 0.0248$ D. Color pale blue. Made from H_2O solution.

$Rb_2Cu(SeO_4)_2 \cdot 6H_2O$ is monoclinic[62] with $a : b : c = 0.750 : 1 : 0.507$, $\beta = 75° \ 16'$. Crystals 001 tablets with perfect $20\bar{1}$ and distinct 010 cleavages. G. = 2.84. The optic plane is 010; $Z \wedge c = -66° \ 55'$, $X \wedge 20\bar{1}$ cleavage = $18° \ 14'$. $(+)$ $2V = 52° \ 58'$ C, $53° \ 11'$ D, $53° \ 43'$ F, $\rho < v$ weak. $N_g = 1.5286$ C, 1.5318 D, 1.5396 F, $N_m = 1.5152$ C, 1.5183 D, 1.5257 F, $N_g = 1.5122$ C, 1.5153 D, 1.5225 F, $N_g - N_p = 0.0165$ D. Color pale blue. Made from H_2O solution.

$(NH_4)_2Cu(SeO_4)_2 \cdot 6H_2O$ is monoclinic[62] with $a : b : c = 0.748 : 1 : 0.515$, $\beta = 74° \ 30'$. Crystals short prismatic with perfect $20\bar{1}$ and 010 cleavages. G. = 2.22. The optic plane is 010; $Z \wedge c = +102° \ 42'$, $X \wedge 20\bar{1}$ cleavage = $28° \ 24'$. $(-)$ $2V = 55° \ 42'$ C, $55° \ 7'$ D, $53° \ 48'$ F, $\rho > v$ weak. $N_g = 1.5352$ C, 1.5387 D, 1.5469 F, $N_m = 1.5309$ C, 1.5344 D, 1.5424 F, $N_p = 1.5166$ C, 1.5201 D, 1.5278 F, $N_g - N_p = 0.0186$ D. Color pale blue. Made from H_2O solution.

$Cs_2Cu(SeO_4)_2 \cdot 6H_2O$ is monoclinic[62] with $a : b : c = 0.740 : 1 : 0.498$, $\beta = 74° \ 18'$. Crystals clinodomatic with perfect $20\bar{1}$ and distinct 010 cleavages. G. = 3.07. The optic plane is 010; $Z \wedge c = -52° \ 48'$, $X \wedge 20\bar{1}$ cleavage = $40° \ 53'$. $(+)$ $2V = 48° \ 20'$ C, $48° \ 26'$ D, $48° \ 42'$ F, $\rho < v$ very weak. $N_g = 1.5360$ C, 1.5394 D, 1.5462 F, $N_m = 1.5264$ C, 1.5298 D, 1.5372 F, $N_p = 1.5248$ C, 1.5282 D, 1.5355 F, $N_g - N_p = 0.0112$ D. Color pale blue. Made from H_2O solution.

$Tl_2Cu(SeO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.753 : 1 : 0.505$, $\beta = 75° \ 1'$. Crystals short prismatic to basal tablets with perfect $20\bar{1}$ cleavage. G. = 3.94. The optic plane is 010; $Z \wedge c = -14° \ 25'$; $X \wedge 20\bar{1}$ cleavage = $33° \ 53'$. $(-)$ $2V = 85° \ 13'$ C, $85° \ 9'$ D, $84° \ 56'$ F. $N_g = 1.6662$ C, 1.6720 D, 1.6867 F, $N_m = 1.6511$ C, 1.6565 D, 1.6709 F, $N_p = 1.6345$ C, 1.6396 D, 1.6537 F, $N_g - N_p =$

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[62] A. E. H. Tutton: *Proc. Roy. Soc.*, A, XCVIII, 1921, p. 67.

[63] A. E. H. Tutton: *Proc. Roy. Soc.*, XCVI, A, 1920, p. 156.

0.0324 D. Color bright blue. Made from H_2O solution with copper selenate in excess.

$K_2Co(SeO_4)_2 \cdot 6H_2O$ is monoclinic[63] with $a : b : c = 0.752 : 1 : 0.506$, $\beta = 75° 43'$. Crystals short prismatic to 001 tablets with perfect $20\bar{1}$ cleavage. G = 2.53. The optic plane is 010; $Z \wedge c = +98° 54'$, $X \wedge 20\bar{1}$ cleavage = 32° 25′. (+) 2V = 62° 13′ C, 62° 19′ D, 62° 27′ F, $\rho < v$ very weak. $N_g = 1.5347$ C, 1.5380 D, 1.5456 F, $N_m = 1.5186$ C, 1.5218 D, 1.5291 F, $N_p = 1.5127$ C, 1.5158 D, 1.5231 F, $N_g - N_p = 0.0222$ D. Color ruby red. Formed from H_2O solution.

$Rb_2Co(SeO_4)_2 \cdot 6H_2O$ is monoclinic[63] with $a : b : c = 0.743 : 1 : 0.052$, $\beta = 74° 46'$. Crystals 001 tablets to short prismatic with perfect $20\bar{1}$ cleavage. G. = 2.84. The optic plane is 010; $Z \wedge c = +102° 50'$, $X \wedge 20\bar{1}$ cleavage = 28° 41′. (+) 2V = 73° 41′ C, 73° 37′ D, 73° 33′ F, $\rho > v$ very weak. $N_g = 1.5334$ C, 1.5369 D, 1.5446 F, $N_m = 1.5225$ C, 1.5256 D, 1.5332 F, $N_p = 1.5168$ C, 1.5199 D, 1.5273 F, $N_g - N_p = 0.0170$ D. Color ruby red. Formed from H_2O solution.

$(NH_4)_2Co(SeO_4)_2 \cdot 6H_2O$ is monoclinic[63] with $a : b : c = 0.745 : 1 : 0.503$, $\beta = 73° 37'$. Crystals 001 tablets with 110 and 011 faces. Perfect $20\bar{1}$ and poor 010 cleavages. G. = 2.23. The optic plane is 010; $Z \wedge c = +92° 23'$ $X \wedge 20\bar{1}$ cleavage = 39° 30′. (+) 2V = 82° 6′ C, 82° 14′ D, 82° 28′ F, $\rho < v$ very weak. $N_g = 1.5382$ C, 1.5417 D, 1.5496 F, $N_m = 1.5292$ C, 1.5327 D, 1.5401 F, $N_p = 1.5228$ C, 1.5261 D, 1.5335 F, $N_g - N_p = 0.0156$ D. Color ruby red. Formed from H_2O solution.

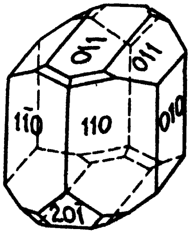

FIG. 250.—A crystal habit of $(NH_4)_2Mg(CrO_4)_2 \cdot 6H_2O$. (After Tutton.)

$Cs_2Co(SeO_4)_2 \cdot 6H_2O$ is monoclinic[63] with $a : b : c = 0.731 : 1 : 0.499$, $\beta = 73° 42'$. Crystals clinodomatic with perfect $20\bar{1}$ cleavage. G. = 3.09. The optic plane is 010; $Z \wedge c = -70° 37'$, $X \wedge 20\bar{1}$ cleavage = 22° 9′. (+) 2V = 87° 8′ C, 86° 48′ D, 86° 32′ F, $\rho > v$ very weak. $N_g = 1.5418$ C, 1.5453 D, 1.5531 F, $N_m = 1.5365$ C, 1.5399 D, 1.5475 F, $N_p = 1.5321$ C, 1.5354 D, 1.5430 F, $N_g - N_p = 0.0099$ D. Color ruby red. Formed from H_2O solution.

$Tl_2Co(SeO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.746 : 1 : 0.502$, $\beta = 74° 20'$. Crystals thick 001 tablets with 110 prominent. Distinct $20\bar{1}$ cleavage. G. = 4.00. The optic plane is 010; $Z \wedge c = -8° 22'$, $X \wedge 20\bar{1}$ cleavage = 39° 45′. (−) 2V = 66° 15′ C, 66° 42′ D, 67° 36′ F. $N_g = 1.6550$ C, 1.6590 D, 1.6706 F, $N_m = 1.6495$ C, 1.6535

D, 1.6646 F, N_p = 1.6402 C, 1.6442 D, 1.6552 F, $N_g - N_p$ = 0.0148 D. Color ruby red. Made from H_2O solution with cobalt selenate in excess.

$K_2Ni(SeO_4)_2 \cdot 6H_2O$ is monoclinic[64] with $a : b : c = 0.747 : 1 : 0.506$, $\beta = 75^\circ 33'$. Crystals 001 tablets to short prismatic with distinct $20\bar{1}$ cleavage. G. = 2.56. The optic plane is 010; $Z \wedge c = +96^\circ 59'$, $X \wedge 20\bar{1}$ cleavage $= 34^\circ 15'$. (+) $2V = 72^\circ 45'$ C, $72^\circ 48'$ D, $72^\circ 56'$ F, $\rho < v$ very weak. N_g = 1.5392 C, 1.5427 D, 1.5507 F, N_m = 1.5237 C, 1.5272 D, 1.5344 F, N_p = 1.5147 C, 1.5181 D, 1.5251 F, $N_g - N_p$ = 0.0246 D. Color bright green. Made from H_2O solution.

$Rb_2Ni(SeO_4)_2 \cdot 6H_2O$ is monoclinic[64] with $a : b : c = 0.740 : 1 : 0.503$, $\beta = 74^\circ 40'$. Crystals 001 tablets to short prismatic with distinct $20\bar{1}$ cleavage. G. = 2.86. The optic plane is 010; $Z \wedge c = +99^\circ 59'$, $X \wedge 20\bar{1}$ cleavage $= 31^\circ 23'$. (+) $2V = 82^\circ 22'$ C, $82^\circ 13'$ D, $81^\circ 58'$ F, $\rho > v$ very weak. N_g = 1.5356 C, 1.5390 D, 1.5466 F, N_m = 1.5258 C, 1.5291 D, 1.5362 F, N_p = 1.5166 C, 1.5198 D, 1.5268 F, $N_g - N_p$ = 0.0192 D. Color bright green. Made from H_2O solution.

$(NH_4)_2Ni(SeO_4)_2 \cdot 6H_2O$ is monoclinic[64] with $a : b : c = 0.740 : 1 : 0.505$, $\beta = 73^\circ 43'$. Crystals thick 001 tablets with perfect $20\bar{1}$ and poor 010 cleavages. G. = 2.24. The optic plane is 010; $Z \wedge c = +92^\circ 0'$, $X \wedge 20\bar{1}$ cleavage $= 39^\circ 31'$. (+) $2V = 86^\circ 19'$ C, $86^\circ 21'$ D, $86^\circ 29'$ F, $\rho < v$ very weak. N_g = 1.5424 C, 1.5460 D, 1.5539 F, N_m = 1.5337 C, 1.5370 D, 1.5447 F, N_p = 1.5251 C, 1.5285 D, 1.5360 F, $N_g - N_p$ = 0.0185 D. Color bright green. Made from H_2O solution.

$Cs_2Ni(SeO_4)_2 \cdot 6H_2O$ is monoclinic[64] with $a : b : c = 0.729 : 1 : 0.499$, $\beta = 73^\circ 49'$. Crystals clinodomatic to 001 tablets with distinct $20\bar{1}$ cleavage. G. = 3.11. The optic plane is 010; $Z \wedge c = -73^\circ 9'$, $X \wedge 20\bar{1}$ cleavage $= 24^\circ 26'$. (−) $2V = 82^\circ 43'$ C, $83^\circ 8'$ D, $83^\circ 43'$ F, $\rho < v$ weak. N_g = 1.5456 C, 1.5489 D, 1.5568 F, N_m = 1.5417 C, 1.5450 D, 1.5525 F, N_p = 1.5363 C, 1.5395 D, 1.5467 F, $N_g - N_p$ = 0.0094 D. Color deep green. Made from H_2O solution.

$Tl_2Ni(SeO_4)_2 \cdot 6H_2O$ is monoclinic[49] with $a : b : c = 0.746 : 1 : 0.502$, $\beta = 74^\circ 24'$. Crystals nearly equant with 110, 001, and 011 prominent. Distinct $20\bar{1}$ cleavage. G. = 3.99. The optic plane is 010; $Z \wedge c = 10^\circ 19'$, $X \wedge 20\bar{1}$ cleavage $= 38^\circ 0'$. (−) $2V = 58^\circ 10'$ C, $58^\circ 59'$ D, $60^\circ 53'$ F, N_g = 1.6517 C, 1.6560 D, 1.6709 F, N_m =

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[64] A. E. H. Tutton: *Trans. Roy. Soc.*, A, 217, 1918, p. 199.

1.6459 C, 1.6498 D, 1.6643 F, N_p = 1.6339 C, 1.6378 D, 1.6523 F, $N_g - N_p$ = 0.0182 D. Color bright green. Made from H_2O solution with nickel selenate in excess.

$Rb_2Mg(CrO_4)_2 \cdot 6H_2O$ is monoclinic[65] with $a : b : c = 0.753 : 1 : 0.495$, $\beta = 75° 11'$. Crystals short prismatic or 001 tablets with good $20\bar{1}$ cleavage. G. = 2.47. The optic plane is normal to 010; $Z \wedge c = -48° 10'$ (5° greater for green than for red light). $X \wedge 20\bar{1}$ cleavage = 0° 35′ and Z is nearly normal to the cleavage. (−) 2V = 88° 4′ C, 86° 32′ D, 84° 31′ Tl, 83° 15′ Cd, $\rho > v$ strong. N_g = 1.6310 Li, 1.6435 Na, 1.6577 Tl, 1.6672 Cd, N_m = 1.6208 Li, 1.6330 Na, 1.6466 Tl, 1.6561 Cd, N_p = 1.6105 Li, 1.6217 Na, 1.6342 Tl, 1.6426 Cd, $N_g - N_p$ = 0.0218 Na. Color yellow. Made from H_2O solution.

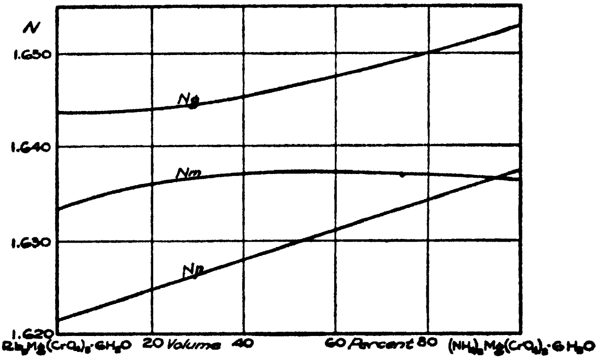

FIG. 251.—Variations in composition and in optic properties in the $Rb_2Mg(CrO_4)_2 \cdot 6H_2O$–$(NH_4)_2Mg(CrO_4)_2 \cdot 6H_2O$ series. (Data of M. W. Porter: *Proc. Roy. Soc.*, A., 109, 1925, p. 78.)

$(NH_4)_2Mg(CrO_4)_2 \cdot 6H_2O$ is monoclinic[65] with $a : b : c = 0.752 : 1 : 0.492$, $\beta = 73° 53'$. Crystals short prismatic as in Fig. 250 or 001 tablets with perfect $20\bar{1}$ cleavage. G. = 1.83. The optic plane is 010 for wave-lengths less than 664 mμ and normal to 010 for wave-lengths greater than 664 mμ (red). $Z \wedge c = +3° 27'$; $X \wedge 20\bar{1}$ cleavage = 52° 31′. (+) 2V = 10° 47′ (684 mμ), 0° (664 mμ), 26° 53′ (589 mμ = Na), 38° 57′ Tl, 44° 37′ Cd. N_g = 1.6390 Li, 1.6531 Na, 1.6687 Tl, 1.6799 Cd, N_m = 1.6250 Li, 1.6371 Na, 1.6509 Tl, 1.6602 Cd, N_p = 1.6248 Li, 1.6363 Na, 1.6489 Tl, 1.6571 Cd, $N_g - N_p$ = 0.0168 Na. Color yellow. Made from H_2O solution.

$(NH_4)_2Mg(CrO_4)_2 \cdot 6H_2O$ is said to be miscible in all proportions[66] with $(NH_4)_2Mg(SO_4)_2 \cdot 6H_2O$, but crystals are not homogeneous (suggesting imperfect miscibility) and very accurate measures are impossible; with 11.6 molecular per cent of the sulphate $N_g = 1.641$, $N_m = 1.627$, $N_p = 1.627$; with 37.2 per cent; $N_g = 1.598$, $N_m = 1.590$, $N_p = 1.589$; with 56.2 per cent, $N_g = 1.560$, $N_m = 1.557$, $N_p = 1.554$; with 73.8 per cent, $N_g = 1.528$, $N_m = 1.525$, $N_p = 1.520$; with 90.0 per cent, $N_g = 1.495$, $N_m = 1.493$, $N_p = 1.491$.

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[65] A. E. H. Tutton and Mary W. Porter: *Min. Mag.*, XVI, 1912, p. 169.

[66] Mary W. Porter: *Proc. Roy. Soc.*, A, CIX, 1925, p. 78.

$(NH_4)_2Mg(CrO_4)_2 \cdot 6H_2O$ is miscible in all proportions[66] with $Rb_2Mg(CrO_4)_2 \cdot 6H_2O$. In such mix-crystals the refractive index for vibrations along *b* is directly proportional to the volume (sensibly = molecular) composition, while the other indices are curvilinear functions of the composition. The variations in properties are shown in Fig. 251.

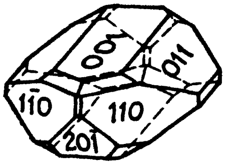

FIG. 252.—A crystal habit of $Cs_2Mg(CrO_4)_2 \cdot 6H_2O$. (After Tutton).

$Cs_2Mg(CrO_4)_2 \cdot 6H_2O$ is monoclinic[65] with $a : b : c = 0.743 : 1 : 0.489$, $\beta = 73° 56'$. Crystals clinodomatic, as in Fig. 252, to short prismatic with good $20\bar{1}$ cleavage. G. = 2.75. The optic plane is normal to 010; $Z \wedge c = -9° 22'$; $X \wedge 20\bar{1}$ cleavage $= 37° 34'$. (+) $2V = 67° 7'$ C, $67° 3'$ D, $66° 33'$ Tl, $65° 57'$ Cd, $\rho > v$ distinct. $N_g = 1.6244$ Li, 1.6547 Na, 1.6683 Tl, 1.6778 Cd, $N_m = 1.6310$ Li, 1.6425 Na, 1.6552 Tl, 1.6640 Cd, $N_p = 1.6257$ Li, 1.6369 Na, 1.6493 Tl, 1.6578 Cd, $N_g - N_p = 0.0178$ Na. Color bright yellow. Made from H_2O solution.

$K_6Fe(CrO_4)_4 \cdot 6H_2O$ is monoclinic[67] with G. = 1.45 and $N_m = 1.556$.

11. ANHYDROUS SULPHATES, ETC., OF TRIVALENT AND MONOVALENT BASES.

$K_2Al_2(SO_4)_4$ is hexagonal[67a] in crystals showing rhombohedrons, prisms and the base, with micaceous 0001 cleavage. Uniaxial negative with $N_o = 1.545\pm$, $N_e = 1.533\pm$, $N_o - N_e = 0.012\pm$. Colorless.

12. HYDROUS SULPHATES, ETC., OF TRIVALENT AND MONOVALENT BASES

ALUM GROUP

The alum group includes hydrous isometric double sulphates (and related salts) of trivalent and monovalent bases with twelve molecules of water. Many salts are included.

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[67] *Int. Crit. Tables*, I, 1926, p. 157.

[67a] Salt prepared by E. Posnjak—properties measured by H. E. Merwin—personal communication, Mar. 25, 1931.

$NaAl(SO_4)_2 \cdot 12H_2O$ seems to have two or three crystal phases; the isometric phase, which alone belongs to the alum group, is unstable and not certainly known in nature; it is called *sodium alum* or *sodalumite* and has G. = 1.69; it crystallizes in octahedrons which may show cubic faces; isotropic with N = 1.4365 C, 1.4388 D, 1.4441 F, F − C = 0.0076. Colorless. The same compound (perhaps only $11H_2O$) is found only in fibrous aggregates with H. = 3, G. = 1.73. Soluble in H_2O. Uniaxial negative with $N_o = 1.458$, $N_e = 1.432$, $N_o - N_e = 0.026$. The natural substance is called *mendozite*. This compound also crystallizes in monoclinic 100 plates with 110, 011, and 211 which have $a : b : c = 2.506 : 1 : 0.913$, $\beta = 70° 59'$. Perfect 010 cleavage (Larsen [68]); perfect 100 cleavage (Surginow [69]). H. = 3. G. = 1.76. The optic plane and X are normal to 010; $Y \wedge c = 30°$ (Larsen), $-37°$ (Soret). (−) 2V = 56° with slight dispersion (Larsen), with distinct crossed dispersion (Soret). $N_g = 1.463$, $N_m = 1.461$, $N_p = 1.449$, $N_g - N_p = 0.014$ (Larsen). Colorless. Forms from solution above 20° C.

$KAl(SO_4)_2 \cdot 12H_2O$ also seems to have two or three crystal phases. The isometric phase, called *potassium alum* or *potassalumite*, forms octahedral or cubic crystals without cleavage having H. = 2, G. = 1.76; N = 1.4540 C, 1.4564 D, 1.4600 F, F − C = 0.010. Colorless. Another phase seems to be hexagonal and is uniaxial negative (Larsen[70]) with $N_o = 1.456$, $N_e = 1.429$, $N_o - N_e = 0.027$. Colorless. The natural substance is called *kalinite*. A third crystal phase is probably monoclinic; fibrous and platy; the optic plane and Z are normal to the plates and $Y \wedge c$ (= elongation) = 13° (Larsen [70]). (−) 2V = 52° with slight dispersion. $N_g = 1.458$, $N_m = 1.452$, $N_p = 1.430$, $N_g - N_p = 0.028$. Colorless. Found in Australia. $KAl(SO_4)_2 \cdot 12H_2O$ is *alum* in the narrowest sense. It intercrystallizes with many other alums and such intercrystallizations seem to be submicroscopic lamellar intergrowths (rather than true mix-crystals) and therefore birefringent; such intergrowths are optically negative in the case of KAl alum with NH_4Al (equal molecular parts) or NH_4Cr or KFe or NH_4Fe; they are optically positive in the case of KAl with KCr (?) or with an excess of KFe or of NH_4Fe.

$NH_4Al(SO_4)_2 \cdot 12H_2O$ is isometric; crystals octahedral with H. = 2, G. = 1.64. Isotropic with N = 1.4569 C, 1.4594 D, 1.4648 F, F − C = 0.0079. Colorless. The natural substance, called *tschermigite*,

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[68] *U. S. Geol. Surv. Bull.* 679, 1921, p. 108.

[69] *Zeit. Kryst.*, LI, 1913, p. 104.

[70] *U. S. Geol. Surv. Bull.*, 679, 1921, p. 94.

The following salts also belong to the alum group.[70a]

Salt	G.	N(C)	N(D)	N(F)	Disp. F-C
$RbAl(SO_4)_2.12H_2O$	1.89	1.4542	1.4566	1.4619	0.0077
$CsAl(SO_4)_2\cdot 12H_2O$	1.97	1.4562	1.4586	1.4639	0.0077
$TlAl(SO_4)_2\cdot 12H_2O$	2.33	1.4944	1.4975	1.5046	0.0102 Also strongly biref.
$RbV(SO_4)_2\cdot 12H_2O$	1.915	....	1.469		
$NH_4V(SO_4)_2\cdot 12H_2O$	1.69	....	1.475		
$CsV(SO_4)_2\cdot 12H_2O$	2.03	....	1.478		
$TlV(SO_4)_2\cdot 12H_2O$	2.34	....	1.514		
$KCr(SO_4)_2\cdot 12H_2O$	1.85	1.4787	1.4814	1.4875	0.0088
$NH_4Cr(SO_4)_2\cdot 12H_2O$	1.73	1.4813	1.4842	1.4904	0.0091
$RbCr(SO_4)_2\cdot 12H_2O$	1.97	1.4787	1.4815	1.4878	0.0091
$CsCr(SO_4)_2\cdot 12H_2O$	2.04	1.4784	1.4810	1.4872	0.0088
$TlCr(SO_4)_2\cdot 12H_2O$	2.39	1.5192	1.5228	1.5308	0.0116
$CsMn(SO_4)_2\cdot 12H_2O$	...	1.483± Li			
$KFe(SO_4)_2\cdot 12H_2O$	1.83	1.4783	1.4817	1.4893	0.0110
$NH_4Fe(SO_4)_2\cdot 12H_2O$	1.72	1.4815	1.4848	1.4929	0.0114 Opt. anom.
$NH_4Fe(SO_4)_2\cdot 12H_2O$	....	1.4821	1.4854	1.4934	0.0113 Opt. anom.
$RbFe(SO_4)_2\cdot 12H_2O$	1.92	1.4789	1.4823	1.4900	0.0111
$CsFe(SO_4)_2\cdot 12H_2O$	2.06	1.4804	1.4838	1.4914	0.0110
$TlFe(SO_4)_2\cdot 12H_2O$	2.38	1.5194	1.5237	1.5328	0.0134
$KGa(SO_4)_2\cdot 12H_2O$	1.90	1.4630	1.4653	1.4709	0.0079
$NH_4Ga(SO_4)_2\cdot 12H_2O$	1.78	1.4658	1.4684	1.4741	0.0083
$RbGa(SO_4)_2\cdot 12H_2O$	1.96	1.4633	1.4658	1.4713	0.0080
$CsGa(SO_4)_2\cdot 12H_2O$	2.11	1.4624	1.4650	1.4703	0.0079
$TlGa(SO_4)_2\cdot 12H_2O$	2.48	1.5035	1.5067	1.5139	0.0104
$NH_4In(SO_4)_2\cdot 12H_2O$	2.01	1.4635	1.4664	1.4723	0.0088 (Unstable)
$RbIn(SO_4)_2\cdot 12H_2O$	2.06	1.4613	1.4638	1.4696	0.0083 (Unstable)
$CsIn(SO_4)_2\cdot 12H_2O$	2.24	1.4628	1.4652	1.4711	0.0083
$RbTi(SO_4)_2\cdot 12H_2O$	....	1.465 Li			
$CsTi(SO_4)_2\cdot 12H_2O$	....	1.472 Li	1.4736	1.476 gr.	
$NH_4Rh(SO_4)_2\cdot 12H_2O$	....	1.5073 Li	1.5103	1.5150 gr.	
$RbRh(SO_4)_2\cdot 12H_2O$	....	1.498± Li	1.501±	1.504± gr.	
$CsRh(SO_4)_2\cdot 12H_2O$	....	1.5063 Li	1.5077	1.5112 gr.	
$TlRh(SO_4)_2\cdot 12H_2O$	....	1.546 Li	1.548	1.549 gr. (Approx.)	
$KAl(SeO_4)_2\cdot 12H_2O$	2.00	1.4773	1.4801	1.4868	0.0095 Opt. anom.
$RbFe(SeO_4)_2\cdot 12H_2O$	2.13	1.5047 Li	1.5070	1.5119 gr.	
$CsFe(SeO_4)_2\cdot 12H_2O$	3.62	1.5088 Li	1.5116	1.5162 gr.	

[70a] New measures, similar to those given above, reported by E. Widmer (*Zeit. Kryst.*, LX, 1924, pp. 195,206) for KAl, RbAl, CsAl, TlAl, KCr, RbCr, CsCr, and TlCr alums.

is rare. Optic anomalies are easily produced in it by pressure. NH_4Al alum intercrystallizes apparently as submicroscopic lamellar intergrowths with many other alums; such intergrowths are optically negative in the case of NH_4Al with KCr, or NH_4Cr; they are optically positive in the case of NH_4Al with NH_4Fe or with an excess of KCr or of NH_4Cr.

The color of the alum salts seems to depend largely upon the trivalent base; thus, aluminum alums are all colorless; vanadium alums are all violet; chromium alums are violet to dark red; the manganese alum is garnet red; iron alums are colorless, when pure and freshly prepared, but usually violet; gallium and indium alums are all colorless; titanium alums are reddish violet, rhodium alums are yellow to orange; the selenate alums are almost black.

$4(NH_4)_2O \cdot Mn_2O_3 \cdot 13MoO_3 \cdot 9H_2O$ is rhombohedral[71] with $\alpha = 104° 24'$. Uniaxial positive with $N_o = 1.757, N_e = 1.819, N_e - N_o = 0.062$. Pleochroic with $X = O =$ clear yellow, $Z = E =$ orange yellow.

$4K_2O \cdot Mn_2O_3 \cdot 13MoO_3 \cdot 9H_2O$ is rhombohedral[71] with $\alpha = 104° 4'$. G. = 3.43. Uniaxial positive without anomalies and similar to $4(NH_4)_2 \cdot Mn_2O_3 \cdot 13MoO_3 \cdot 9H_2O$. Pleochroic with $X = O =$ canary yellow, $Z = E =$ orange.

$NaAl(SO_4)_2 \cdot 6H_2O$ is monoclinic (?); crystals 100 laths or vertical fibers. Multiple twinning common. H. = 1. G. = 2.3. Insoluble in acid. The optic plane and Z are normal (or nearly normal) to 010; $Y \wedge c = 30° \pm$. (+) $2V = 60°$. $N_g = 1.499$, $N_m = 1.488$, $N_p = 1.484$, $N_g - N_p = 0.015$. Colorless. Made by partial dehydration of sodalumite in a desiccator.[72] The natural substance, called *tamarugite*, is found in Chile.

13. HYDROUS SULPHATES, ETC., OF TRIVALENT AND DIVALENT BASES

$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$ is hexagonal[72a] and long prismatic with G. = 1.48. Uniaxial negative with negative elongation and $N_o = 1.464$ Na, $N_e = 1.458$, $N_o - N_e = 0.006$. Colorless. Formed by mixing 9 parts of $3CaO \cdot 5Al_2O_3$ and 1 part of $CaSO_4$ in water. Dehydrates at 110° C. to $7H_2O$ with longitudinal cracking, a change in sign of elongation to positive and an increase in the mean index of refraction to 1.50±. Rehydration in moist air causes the sign of elongation to change back to negative and the mean index of refraction to decrease to 1.45±. Apparently takes $3CaO \cdot Al_2O_3 \cdot nH_2O$ in crystal solution to a maximum which gives a ratio of $Al_2O_3 : CaSO_4 = 2 : 5$. It seems to be one of the products made by the action of sulphate waters on Portland cement. This substance is thought to be the same as the natural mineral known as *ettringite*.

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[71] F. Zambonini and V. Caglioti: *Gazz. Chim. Ital.*, LIX, 1929, pp. 400–460.

[72] E. S. Larsen: *U. S. Geol. Surv. Bull.* 679, 1921, p. 109.

[72a] Wm. Lerch, F. W. Ashton and R. H. Bogue: "The Sulphoaluminates of Calcium," *Bur. Stand. Jour. Res.*, II, 1929, p. 715.

$3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O$ is hexagonal[72] in basal plates with G. = 1.95. Uniaxial negative with positive elongation and $N_o = 1.504$ Na, $N_e = 1.488$, $N_o - N_e = 0.016$. Colorless. Dehydration at 110° C. to $6H_2O$ alters the substance so that it is somewhat variable in properties with $N_g = 1.529$–1.535 and $N_p = 1.510$–1.527. Not as stable as $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$. It seems to be one of the products of reaction of sulphate water on Portland Cement.

14. SULPHATES CONTAINING URANIUM (OR URANATE-SULPHATES?)

$K_2UO_2(SO_4)_2 \cdot 2H_2O$ is orthorhombic[73] with $a : b : c = 0.589 : 1 : 0.625$. Crystals 001 tablets or pyramidal with 001 cleavage. The optic plane is 100; X = c. (−) 2V = 60° (calc.). $N_g = 1.563$, $N_m = 1.522$, $N_p = 1.509$ for 720 mμ; $N_g = 1.5705$, $N_m = 1.5266$, $N_p = 1.5144$, $N_g - N_p = 0.0561$ for 580 mμ; $N_g = 1.583$, $N_m = 1.535$, $N_p = 1.520$ for 500 mμ. Not pleochroic.

15. ANHYDROUS POLYTHIONATES AND POLYCHROMATES

$Na_{10}Cu_2Ag_4(S_2O_3)_8 \cdot 6NH_3$ is tetragonal with $c = 0.84$. Crystals prismatic with imperfect 001 cleavage. Uniaxial negative with $N_o = ?$, $N_e = 1.7\pm$. Color deep blue with X = pale sapphire blue and Z = deep cobalt blue.

$4(NH_4)_2S_2O_3 \cdot AgBr \cdot NH_4Br$ is tetragonal with $c = 0.63$. Uniaxial negative with $N_o = 1.6769$, $N_e = 1.6294$, $N_o - N_e = 0.0475$.

$K_2S_2O_6$ is trigonal with $c = 0.647$. Crystals short to long hexagonal prisms. G. = 2.28. Uniaxial positive[74] with $N_o = 1.4532$ C, 1.4550 D, 1.4595 F, $N_e = 1.5119$ C, 1.5153 D, 1.5239 F, $N_e - N_o = 0.0603$ D.

$Rb_2S_2O_6$ is trigonal with $c = 0.631$. Crystals hexagonal prisms.

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[73] E. L. Nichols and H. L. Howes: *Carn. Inst. Publ.* 298, 1919, p. 220.

[74] See also H. Rose: *N. Jahrb. Min. Beil. Bd.*, XXIX, 1910, p. 53.

Uniaxial positive[75] with $N_o = 1.4544$ C, 1.4565 D, 1.4613 F, $N_e = 1.5034$ C, 1.5068 D, 1.5153 F, $N_e - N_o = 0.0503$ D.

$Cs_2S_2O_6$ is trigonal with $c = 0.632$. Crystals prismatic. Uniaxial positive[75] with $N_o = 1.5207$ C, 1.5230 D, 1.5285 F, $N_e = 1.5405$ C, 1.5438 D, 1.5518 F, $N_e - N_o = 0.0208$.

$K_2S_3O_6$ is orthorhombic with $a : b : c = 0.717 : 1 : 0.419$; crystals prismatic or tabular. No distinct cleavage. G. = 2.34. The optic plane is 010; $X = c$. (−) 2V = 72° (68°) Na. For 691 mμ : $N_g = 1.596$, $N_m = 1.5591$, $N_p = 1.4900$, $N_g - N_p = 0.106$. For 656 mμ : $N_m = 1.5607$, $N_p = 1.4909$. For 589 mμ : $N_g = 1.602$, $N_m = 1.5641$, $N_p = 1.4934$, $N_g - N_p = 0.1086$. For 436 mμ : $N_g = 1.621$, $N_m = 1.5805$, $N_p = 1.5040$, $N_g - N_p = 0.117$.

$Rb_2S_3O_6$ is orthorhombic with $a : b : c = 0.706 : 1 : 0.418$. Crystals prismatic. G. = 2.85. The optic plane is 010; $X = c$. (−) 2V = 62° 33′. $N_g = 1.5867$, $N_m = 1.5580$, $N_p = 1.4874$, $N_g = 1.4903$, $N_g - N_p = 0.0993$ Na.

$K_2S_4O_6$ is monoclinic[75a] with $a : b : c = 0.930 : 1 : 1.267$, $\beta = 75° 44′$. Crystals 100 tablets or prismatic with distinct 100 cleavage. G. = 2.30. The optic plane is 010; $Z \wedge c = 33°$ C, $33\frac{1}{2}°$ F, in the obtuse angle β. (+) 2V = 67° C, $68\frac{1}{2}°$ F. $N_g = 1.6435\pm$, $N_m = 1.6057\pm$, $N_p = 1.5896\pm$, $N_g - N_p = 0.0539\pm$. Dispersion (F − C) for $N_m = 0.0171$. Colorless.

CaS_4O_6 forms biaxial crystals[1] with (+) 2V = 32°±, $N_g = 1.675\pm$, $N_m = 1.540\pm$, $N_p = 1.535\pm$, $N_g - N_p = 0.140\pm$. Colorless.

$(NH_4)_2S_2O_8$ is monoclinic with $a : b : c = 1.296 : 1 : 1.187$, $\beta = 76° 12′$. Crystals basal tablets or elongated parallel to b. Imperfect 001 cleavage. G. = 1.98. The optic plane is 010; $Z \wedge c = +27°$. (+) 2V = 24°, $\rho < v$ moderate. $N_g = 1.5866$, $N_m = 1.5016$, $N_p = 1.4981$, $N_g - N_p = 0.0885$. Colorless. Made from H_2O solution evaporated at ordinary temperature.

$Rb_2S_2O_8$ is monoclinic with $a : b : c = 1.281 : 1 : 1.188$, $\beta = 76° 32′$; crystals basal tablets or elongated parallel to b. No distinct cleavage. G. = 3.13. The optic plane is 010; $Z \wedge c = +26.5°$. (+) 2V = 35°, $\rho < v$ weak. $N_g = 1.5719$, $N_m = 1.4888$, $N_p = 1.4812$, $N_g - N_p = 0.0907$. Made from warm solution.

$K_2S_2O_8$ is triclinic with $a : b : c = 0.576 : 1 : 0.574$, $\alpha = 98° 33′$,

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[75] *Zeit. Kryst.*, LVIII, 1923, p. 461; corrected in *Zeit. Kryst.*, LIX, 1925, p. 249. Rose (*Cent. Min.*, 1917, p. 85) gives $N_o = 1.444$ Na, $N_e = 1.491$, $N_e - N_o = 0.047$ for $Cs_2S_2O_6$.

[75a] Salt prepared by E. T. Allen—properties measured by H. E. Merwin—personal communication, Mar. 25, 1931.

$\beta = 94° 2'$, $\gamma = 88° 39'$. Crystals 010 tablets. Twinning on 010. Distinct 010 cleavage. G. = 2.48. The optic axes are in the positive octant. (+) 2V = 29° 32′. $N_g = 1.5657$, $N_m = 1.4669$, $N_p = 1.4609$, $N_g - N_p = 0.1048$. Made from solution at ordinary temperature.

$K_2Cr_2O_7$ is triclinic with $a : b : c = 0.558 : 1 : 0.551$, $\alpha = 82° 0'$, $\beta = 90° 51'$, $\gamma = 83° 47'$. Crystals prismatic or thick 010 tablets. Twinning on 010 and others. Perfect 010, distinct 100 and 001 cleavages. G. = 2.69. The optic plane is nearly normal to 001 between 100 and $0\bar{1}0$. X makes angles of 86° 27′, 68° 6′ and 13° 43′ with normals to 100, $0\bar{1}0$ and 001; Z makes angles of 77° 5′, 23° 5′ and 76° 21′ with normals to 100, $0\bar{1}0$ and $00\bar{1}$. (+) 2V = 52° 24′ Li, 51° 53′ D, $\rho > v$. $N_g = 1.8197$, $N_m = 1.7380$, $N_p = 1.7202$, $N_g - N_p = 0.0995$. Color aurora red; pleochroic with X = red, Z = yellow. Made from the warm solution.

16. HYDROUS POLYTHIONATES, POLYCHROMATES, ETC.

$CaS_2O_6 \cdot 4H_2O$ is trigonal with $c = 1.50$. Crystals six-sided basal plates with imperfect basal cleavage. G. = 2.18. Uniaxial negative[76] with $N_o = 1.5456$ B, 1.5516 D, 1.5580 F, $N_e = 1.5369$ B, 1.5414 D, 1.5467 F, $N_o - N_e = 0.0102$ D (Rose); also $N_o = 1.5468$ C, 1.5496 D, 1.5573 F (Topsøe).[77]

$SrS_2O_6 \cdot 4H_2O$ is trigonal with $c = 1.502$. Crystals six-sided basal plates with imperfect basal cleavage. G. = 2.37. Uniaxial negative with $N_o = 1.5266$ C, 1.5296 D, 1.5371 F, $N_e = 1.5232$ C, 1.5252 D, 1.5312 F, $N_o - N_e = 0.0044$ D (Topsøe)[77]; also $N_o = 1.5260$ (672), 1.5297 (579), 1.5357 (492), $N_e = 1.5232$ (672), 1.5262 (579), 1.5310 (492) (Rose[56]).

$PbS_2O_6 \cdot 4H_2O$ is trigonal with $c = 1.516$. Crystals six-sided basal plates or rhombohedrons with no cleavage. G. = 3.25. Uniaxial positive with $N_o = 1.6295$ C, 1.6351 D, 1.6481 F, $N_e = 1.6492$ C, 1.6531 D, 1.6666 F, $N_e - N_o = 0.018$ D (Topsøe);[77] also $N_o = 1.6303$ (672), 1.6366 (579), 1.6480 (492), $N_e = 1.6500$ (672), 1.6557 (579), 1.6672 (492) (Rose[56]). Also slightly biaxial. Made from the cold solution. $PbS_2O_6 \cdot 4H_2O$ forms a continuous series of six-sided crystals with $SrS_2O_6 \cdot 4H_2O$, with rectilinear variation of the refractive indices.[78]

$Li_2S_2O_6 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.966 : 1 : 0.578$.

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[76] H. Rose: *N. Jahrb. Min. Beil. Bd.* XXIX, 1910, p. 74.

[77] Topsøe and Christiansen: Groth: *Chem. Kryst.*, II, 1908, pp. 705–6.

[78] *Zeit. Kryst.*, LII, 1913, p. 48.

Crystals macrodomatic, with perfect 100 cleavage. G. = 2.16. The optic plane is 001; Z = *a*. (+) 2V = 78° 16′, N_g = 1.5763 C, 1.5788 D, 1.5887 F, N_m = 1.5565 C, 1.5602 D, 1.5680 F, N_p = 1.5462 C, 1.5487 D, 1.5548 F, $N_g - N_p$ = 0.0301 D.

$Na_2S_2O_6 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.992 : 1 : 0.598$. Crystals prismatic, with perfect 110 cleavage. G. = 2.19. The optic plane is 010; Z = *a*. (+) 2V = 73° 26′ Li, 75° 14′ Na, 76° 28′ green, $\rho < v$ strong. N_g = 1.5158 Li, 1.5185 Na, 1.5212 gr., N_m = 1.4927 Li, 1.4953 Na, 1.4978 gr., N_p = 1.4803 Li, 1.4820 Na, 1.4838 gr., $N_g - N_p$ = 0.0355 Na.

$K_2Cr_2O_7 \cdot Hg(CN)_2 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.794 : 1 : 1.495$. Crystals short prismatic with 110 cleavage. The optic plane is 100; Z = *c*. (+) 2E = 99° 22′ red, 62° 6′ green, 2V = 57° 18′ red. N_m = 1.591 red, $N_g - N_p$ = ? Made from solution.

$Ag_2S_2O_6 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.988 : 1 : 0.581$. Crystals prismatic with perfect 110 cleavage. G. = 3.62. The optic plane is 001; X = *b*. (−) 2V = 33° 21′ C, 28° 6′ F; N_g = 1.6601 C, 1.6770 F, N_m = 1.6573 C, 1.6748 F, N_p = 1.6272 C, 1.6404 F, $N_g - N_p$ = 0.0329 C, 0.0366 F. Isomorphous with $Na_2S_2O_6 \cdot 2H_2O$.

$K_2S_5O_6 \cdot \frac{3}{2}H_2O$ is orthorhombic with $a : b : c = 0.456 : 1 : 0.305$. Crystals prismatic (110, 010, 011, etc.) or thick 010 tablets terminated by 221 with no distinct cleavage. The optic plane[79] is 010; X = *a*; positive elongation. (−) 2V = 65°±, $\rho > v$. N_g = 1.658, N_m = 1.63±, N_p = 1.570, $N_g - N_p$ = 0.088 (Mason); N_g = 1.655±, N_m = 1.63, N_p = 1.565, $N_g - N_p$ = 0.090 (Merwin[79a]). Colorless. Made from H_2O solution.

$BaS_5O_6 \cdot \frac{7}{2}H_2O$? is orthorhombic in rectangular tablets flattened parallel with the optic plane.[79] (+) 2V = fairly large. N_g = 1.670, N_m = 1.640−, N_p = 1.620−, $N_g - N_p$ = 0.050+. Colorless. Crystallized from H_2O solution by addition of alcohol.

$BaS_2O_6 \cdot 2H_2O$ is monoclinic with $a : b : c = 0.94 : 1 : 1.38$, β = 68° 39′. Crystals varied with perfect 001 cleavage. Twinning on 001. G. = 3.12. The optic plane is 010; $Z \wedge c = -13°$. (+) 2V = 83° 6′–83° 31′ Li, 84° 28′–84° 38′ Na, 87° 18′–87° 38′ green, $\rho < v$ strong. N_g = 1.6055 Li, 1.6072 Na, 1.6090 gr., N_m = 1.5935 Li, 1.5951 Na, 1.5976 gr., N_p = 1.5848 Li, 1.5860 Na, 1.5881 gr., $N_g - N_p$ = 0.0212 Na.

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[79] Optic properties determined by C. W. Mason—personal communication, Jan. 31, 1930.

[79a] Personal communication, Mar. 25, 1931.

$BaS_2O_6 \cdot 4H_2O$ is monoclinic with $a : b : c = 1.222 : 1 : 1.127$, $\beta = 85° 44'$. 110 cleavage. Pseudohexagonal by twinning on 110. G. = 3.1. $Z = b$; $X \wedge c = -45°$. (+) $2V = 87° 20'$ red, $89° 42'$ green, $N_m = 1.532$ red, $N_g - N_p$ = strong. Colorless.

$CaS_2O_3 \cdot 6H_2O$ forms biaxial crystals[1] with oblique extinctions. (+) $2V = 60° \pm$ calc. $N_g = 1.605 \pm$, $N_m = 1.560 \pm$, $N_p = 1.545 \pm$, $N_g - N_p = 0.060 \pm$. Colorless.

$Na_2Cr_2O_7 \cdot 2H_2O$ is monoclinic with $a : b : c = 0.57 : 1 : 1.182$, $\beta = 85° 5'$. Crystals basal plates with no cleavage. Deliquescent. G. = 2.53. The optic plane is normal to 010; $Z \wedge c = +13°$. (+) $2V = 83° 42'$, $\rho < v$. $N_g = 1.751$, $N_m = 1.6994$, $N_p = 1.6610$, $N_g - N_p = 0.090$. Made from solution.

$SrCr_2O_7 \cdot 3H_2O$ is monoclinic with $a : b : c = 0.602 : 1 : 0.546$, $\beta = 87° 28'$. Crystals 100 plates. The optic plane is 010; $Z \wedge c = +78°$. (+) $2V = 20° 28'$, $\rho < v$. $N_g = 1.812$ (calc.), $N_m = 1.7174$, $N_p = 1.7146$, $N_g - N_p = 0.0954$. Made from solution.

$Na_2S_2O_3 \cdot 5H_2O$ is monoclinic with $a : b : c = 0.351 : 1 : 0.275$, $\beta = 76° 2'$. Crystals prismatic or 010 laths. G. = 1.7±. The optic plane and Z are normal to 010. $X \wedge c = -41\frac{1}{2}°$ Na ($-42° 18'$ F). (+) $2V = 80° 40'$ Na, $\rho < v$. $N_g = 1.5311$ Li, 1.5360 Na, 1.5405 Tl, $N_m = 1.5038$ Li, 1.5079 Na, 1.5117 Tl, $N_p = 1.4849$ Li, 1.4886 Na, 1.4919 Tl, $N_g - N_p = 0.0474$ Na. Made from H_2O solution.

$MgW_4O_{13} \cdot 8H_2O$ is monoclinic with $a : b : c = 0.676 : 1 : 0.779$, $\beta = 73° 17'$. Crystals 001 plates. The optic plane and Z are normal to 010; $X \wedge c = -66°$. (+) $2V = 77° 50'$, $\rho < v$ weak. $N_m = 1.74$, $N_g - N_p$ = ? Made from barium metatungstate and magnesium sulphate.

$H_8Na_6(MoO_4)_7 \cdot 18H_2O$ is monoclinic with $a : b : c = 2.092 : 1 : 2.024$, $\beta = 76° 35'$. Crystals short columnar (100 and 010), twinned on 100, with imperfect 100 cleavage. The optic plane and X are normal to 010; $Z \wedge c = -85°$ red, $-84° 30'$ Na, $-83°$ blue. (+) $2V = 84° 16'$ red, $84° 6'$ Na, $83°$ blue, $\rho > v$ weak. $N_m = 1.627$, $N_g - N_p$ = strong. Made from HNO_3 solution of sodium molybdate.

$Ce_2(S_2O_6)_3 \cdot 15H_2O$ is triclinic with $a : b : c = 0.592 : 1 : 1.191$. $\alpha = 81° 26'$, $\beta = 105° 21'$, $\gamma = 86° 38'$. Crystals thick 001 tablets with perfect 100 cleavage. G. = 2.29. Both axes visible through 001 with the acute bisectrix inclined to the left and with unsymmetrical dispersion; the optic plane cuts the a axis at about 20°. (−) $2V = 88° 52'$, $\rho > v$ weak. $N_m = 1.507$, $N_g - N_p$ = ? Formed from solution below 15° C.

17. COMPOUNDS OF SULPHATES, ETC., WITH SALTS OF OTHER ACIDS

$(NH_4)_3PdCl_3SO_3 \cdot H_2O$ is trigonal with $c = 0.892$; distinct prismatic cleavage. Uniaxial positive with $N_o = 1.643$ Na, $N_e - N_o =$ strong. Color deep red with X = carmine red, Z = reddish yellow.

$Na_2SO_4 \cdot NaF$ is hexagonal[80] with $c = 1.77$; crystals 0001 tablets with hexagonal outline and trigonal symmetry. Distinct 0001 cleavage. Slowly soluble in H_2O; fuses easily. H. = 3.5. G. = 2.61. Uniaxial positive with $N_o = 1.436$, $N_e = 1.439$, $N_e - N_o = 0.003$. Colorless. The natural substance,[80a] which forms steep rhombohedrons, has been named *schairerite*; it contains about 3.5 per cent Cl replacing F, has no cleavage and has $N_o = 1.440$, $N_e = 1.445$, $N_e - N_o = 0.005$.

$Na_2CO_3 \cdot 2Na_2SO_4$ is orthorhombic[81] with $a : b : c = 0.579 : 1 : 1.213$. Crystals pyramidal in cyclic penetration twins on 101. The optic plane is 001; $X = a$. (+) 2V = moderate. $N_g = 1.480$, $N_m = 1.469$, $N_p = 1.463$, $N_g - N_p = 0.017$. Colorless. Made from H_2O solution above 25° C.

$2NH_4NO_3 \cdot (NH_4)_2SO_4$ is orthorhombic[82] with $a : b : c = 1.106 : 1 : 3.804$;[83] crystals 001 hemimorphic tablets and similar to $(NH_4)_2SO_4$ in crystal habit with 001 cleavage and pseudohexagonal twinning on 110. The optic plane is 010,[82] (or 100[83]); $X = c$. (−) 2V = 64°. $N_g = 1.536$, $N_m = 1.531$, $N_p = 1.521$. $N_g = N_p = 0.015$. Colorless. Made from solution. Another sample of the same composition resembled NH_4NO_3 in crystal habit and had cleavages normal to X and to Y with $N_g = 1.543$, $N_m = 1.528$, $N_p = 1.469$ ($\therefore -$ 2V = 55°). $N_g - N_p = 0.074$.

$Na_6P_2Mo_5O_{23} \cdot 14H_2O$ is orthorhombic with $a : b\ c: = 0.797 : 1 : 1.073$. Crystals prismatic with perfect 102 cleavage. The optic plane is 100; $X = b$. (−) 2V = 51° 18′ Na, $\rho < v$ weak. $N_g = 1.6430$ Li, 1.6520 Na, 1.6610 Tl, $N_m = 1.6328$ Li, 1.6411 Na, 1.6494 Tl, $N_p = 1.5906$ Li, 1.5962 Na, 1.6017 Tl, $N_g - N_p = 0.0558$ Na.

$Sr_2SiW_{12}O_{40} \cdot 16H_2O$ is monoclinic with $a : b : c = 1.845 : 1 : 1.570$, $\beta = 75° 24'$. Crystals prismatic with 110, 100, $10\bar{1}$, 001, 011. The optic plane and X are normal to 010; $Z \wedge c = -17°$. (+) 2V =

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[80] H. W. Foote and J. F. Schairer: *Jour. Am. Chem. Soc.*, LII, 1930, p. 4202.

[80a] W. F. Foshag: *Am. Mineral.*, XVI, 1931, p. 133.

[81] A. F. Rogers: *Am. Jour. Sci.*, CCXI, 1926, p. 473.

[82] Thomas and Hallimond: *Trans. Faraday Soc.*, XX, 1924, p. 56.

[83] E. Jänecke *et al.*: *Zeit. anorg. Chem.*, CLX, 1927, p. 171.

86° 50′ Na, $\rho < v$ very strong. $N_m = 1.749$, $N_g - N_p$ = rather strong. Made from H_2O solution above 50° C.

$Ba_2SiW_{12}O_{40} \cdot 16H_2O$ is monoclinic with $a : b : c = 1.799 : 1 : 1.544$, $\beta = 76° 7'$. Crystals short prismatic with 110, 100, $10\bar{1}$ and 011. The optic plane and X are normal to 010; $Z \wedge c = -14°$. $(-)\ 2V = 78° 44'$ Na, $\rho > v$ very strong. $N_m = 1.816$, $N_g - N_p$ = rather strong. Made from solution above 30° C.

$3(NH_4)_2O \cdot TeO_2 \cdot 6MoO_2 \cdot 7H_2O$ is apparently triclinic in fairly large crystals showing well-developed basal pinacoids and smaller prisms and pyramids. Basal pinacoid plates are usually six-sided and show inclined extinction.[84] $(-)\ 2V = 74° \pm 5°$ (calc.), $N_g = 1.755 \pm 0.003$, $N_m = 1.710 \pm 0.05$, $N_p = 1.639 \pm 0.003$, $N_g - N_p = 0.116$.

IX. PHOSPHATES, ETC.

The phosphates, vanadates, arsenates, and antimonates are included in this division. The arrangement begins with anhydrous acid and normal salts of monovalent bases and of maximum symmetry and continues to hydrous basic salts of several bases and of minimum symmetry. Then follow metaphosphates, phosphites, arsenites, antimonites, hypophosphates, pyrophosphates and pyroantimonates. The division ends with a few phosphates which contain salts of other oxygen acids.

1. ANHYDROUS ACID PHOSPHATES, ETC., OF MONOVALENT BASES

KH_2PO_4 is tetragonal with $c = 0.939$. Crystals simple prismatic (terminated by a pyramid of the same order), as in Fig. 253, with no distinct cleavage. G. = 2.34. Uniaxial negative with $N_o = 1.5064$ C, 1.5095 D, 1.5154 F, $N_e = 1.4664$ C, 1.4684 D, 1.4734 F, $N_o - N_e = 0.0411$ D. Colorless. Made from cold solution.

KH_2AsO_4 is tetragonal with $c = 0.938$. Crystal simple prismatic (terminated by a pyramid of the same order) with G. = 2.88. Uniaxial negative with $N_o = 1.5632$ C, 1.5674 D, 1.5762 F, $N_e = 1.5146$ C, 1.5179 D, 1.5252 F, $N_o - N_e = 0.0495$ D. Colorless.

$NH_4H_2PO_4$ is tetragonal with $c = 1.008$. Crystals prismatic (terminated by the pyramid) with G. = 1.80. Uniaxial negative with $N_o = 1.5212$ C, 1.5246 D, 1.5314 F, $N_e = 1.4768$ C, 1.4792 D, 1.4847 F, $N_o - N_e = 0.0454$ D. Colorless.

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[84] Optic properties measured by Dr. V. A. Vigfusson on crystals prepared by Dr. V. W. Meloche and assistants.

$NH_4H_2AsO_4$ is tetragonal with $c = 1.004$. Crystals prismatic (terminated by the pyramid) with no distinct cleavage. G. = 2.32. Uniaxial negative with $N_o = 1.5721$ C, 1.5766 D, 1.5859 F, $N_e = 1.5186$ C, 1.5217 D, 1.5296 F, $N_o - N_e = 0.549$ D. Colorless.

Ag_2HPO_4 is trigonal with $c = 0.73$. Crystals prisms or 0001 tablets. Very unstable in light or moisture. Uniaxial negative with $N_o = 1.8036$ Na, $N_e = 1.7983$, $N_o - N_e = 0.0053$.

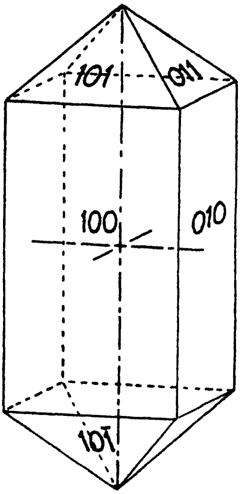

FIG. 253.—A crystal habit of KH_2PO_4.

2. HYDROUS PHOSPHATES, ETC., OF MONOVALENT BASES

$Na_7FP_2O_8 \cdot 19H_2O$ is isometric and octahedral. G. = 2.22. Isotropic with N = 1.449 Li, 1.452 Na, 1.455 Tl. Colorless. Made from a mixture of solutions of sodium phosphate, soda, and sodium fluoride.

$Na_7FAs_2O_8 \cdot 19H_2O$ is isometric and octahedral. Isotropic with N = 1.4657 Li, 1.4693 Na, 1.4726 Tl. Colorless. Made from a mixture of solutions of sodium arsenate, sodium hydroxide and sodium fluoride.

$Na_7FV_2O_8 \cdot 19H_2O$ is isometric and octahedral. Isotropic with N = 1.5171 Li, 1.5230 Na, 1.5284 Tl.

$Na_3PO_4 \cdot 10H_2O$ is isometric[1] in octahedrons and dodecahedrons. Isotropic with N = 1.450. Colorless. Made from hot H_2O solution of sodium phosphate.

$Na_3VO_4 \cdot 10H_2O$ is dimorphous; one phase is isometric and dodecahedral with N = 1.5244 Li, 1.5305 Na, 1.5366 Tl; another phase is in hexagonal basal plates which are uniaxial positive with $N_o = 1.5332$ Li, 1.5398 Na, 1.5460 Tl, $N_e = 1.5408$ Li, 1.5475 Na, 1.5537 Tl, $N_e - N_o = 0.0077$ Na.

$Na_3PO_4 \cdot 12H_2O$ is trigonal with G. = 1.64. Crystals long prismatic with 0001. Uniaxial positive with $N_o = 1.4458$ Na, $N_e = 1.4524$, $N_e - N_o = 0.0066$.

$Na_3AsO_4 \cdot 12H_2O$ is trigonal with G. = 1.78. Crystals prismatic with 0001. Uniaxial positive with $N_o = 1.4553$ Li, 1.4589 Na, 1.4624 Tl, $N_e = 1.4630$ Li, 1.4669 Na, 1.4704 Tl, $N_e - N_o = 0.0080$.

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[1] C. W. Mason: personal communication, Jan. 31, 1930.

$Na_3VO_4 \cdot 12H_2O$ is trigonal. Crystals prismatic with 0001. Uniaxial positive with $N_o = 1.5040$ Li, 1.5095 Na, 1.5150 Tl, $N_e = 1.5173$ Li, 1.5232 Na, 1.5293 Tl, $N_e - N_o = 0.0137$ Na.

$NaH_2PO_4 \cdot H_2O$ is orthorhombic with $a : b : c = 0.934 : 1 : 0.962$; crystals short prismatic. G. = 2.06. The optic plane is 010; X = a. (−) 2V = 29° 0′ Li, 29° 22′ Na, 29° 48′ Tl, $\rho < v$ weak. $N_g = 1.4841$ Li, 1.4873 Na, 1.4902 Tl, $N_m = 1.4821$ Li, 1.4852 Na, 1.4881 Tl, $N_p = 1.4527$ Li, 1.4557 Na, 1.4583 Tl, $N_g - N_p = 0.0316$ Na. Colorless. Made from the syrupy H_2O solution. A second phase is known —also orthorhombic with $a : b : c = 0.817 : 1 : 0.500$.

$NaH_2AsO_4 \cdot H_2O$ is orthorhombic with $a : b : c = 0.817 : 1 : 0.498$. Crystals prismatic. G. = 2.67. The optic plane is 010; X = c. (−) 2V = 67° 15′ Li, 67° 57′ Na, 68° 33′ Tl, $\rho < v$. $N_g = 1.5563$ Li, 1.5607 Na, 1.5647 Tl, $N_m = 1.5494$ Li, 1.5535 Na, 1.5573 Tl, $N_p = 1.5341$ Li, 1.5382 Na, 1.5418 Tl, $N_g - N_p = 0.0225$ Na. Colorless. Made from H_2O solution. A second phase which is monoclinic, is apparently made at higher temperature.

$NaH_2PO_4 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.915 : 1 : 1.569$. Crystals pyramidal or brachydomatic. G. = 1.92. The optic plane is 010; X = c. (−) 2V = 82° 50′. $N_g = 1.4782$ Li, 1.4815 Na, 1.4843 Tl, $N_m = 1.4600$ Li, 1.4629 Na, 1.4655 Tl, $N_p = 1.4376$ Li, 1.4401 Na, 1.4423 Tl, $N_g - N_p = 0.0414$ Na. Made by cooling a warm concentrated solution.

$NaH_2AsO_4 \cdot 2H_2O$ is orthorhombic with $a : b : c = 0.918 : 1 : 1.604$. Crystals pseudo-octahedral with 101, 011, etc. G. = 2.31. The optic plane is 010; Z = c. (+) 2V = 88° 50′, $\rho < v$ weak. $N_g = 1.5265$, $N_m = 1.5021$, $N_p = 1.4794$, $N_g - N_p = 0.0471$ Na.

$NH_4NaHPO_4 \cdot 4H_2O$ or *microcosmic salt* is pseudomonoclinic[2] with $a : b : c = 2.908 : 1 : 1.859$, $\beta = 81° 30′$. Crystals short prismatic as in Fig. 254; no cleavage. H. = 2. G. = 1.57. F. = 79° C. Loses NH_3 and H_2O between 96° and 200° C., changing to $NaPO_3$ which forms sodium phosphate "beads," of importance in blow-pipe work. The optic plane is (nearly) normal to 010; on 001, $X' \wedge 100 = 9° 35′$; on 100, $X' \wedge 001 = 1° 20′$ with strong dispersion; Z is nearly normal to 001. (+) 2V = 35° 34′, $\rho > v$ rather strong. $N_g = 1.469$, $N_m = 1.442$, $N_p = 1.439$, $N_g - N_p = 0.030$. A section parallel to 010 shows two sets of lamellar twinning at about 90°. Colorless. Made from H_2O solution. The natural substance, called *stercorite*, is found in guano.

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[2] A. Schaschek: *Tsch. Min. Pet. Mit.*, XXXII, 1913, p. 402.

$NH_4NaHAsO_4 \cdot 4H_2O$ is monoclinic[2] with $a : b : c = 2.872 : 1 : 1.859$, $\beta = 81° 1'$. Crystals short prismatic. No cleavage. H. = 2. G. = 1.845. The optic plane is 010; $Z \wedge c = +18°$. (+) $2V = 38°$. $N_g = 1.4791$ Na, $N_m = 1.4663$, $N_p = 1.4649$, $N_g - N_p = 0.0142$. Colorless.

$Na_2HPO_4 \cdot 7H_2O$ is monoclinic with $a : b : c = 1.205 : 1 : 1.327$, $\beta = 83° 3'$. Crystals thick prismatic basal plates. G. = 1.68. The optic plane is normal to 010; $Z \wedge c = -72°$. (+) $2V = 39° 33'$ Li, $38° 50'$ Na, $37° 59'$ Tl, $\rho > v$. $N_g = 1.4497$ Li, 1.4526 Na, 1.4552 Tl, $N_m = 1.4395$ Li, 1.4424 Na, 1.4449 Tl, $N_p = 1.4382$ Li, 1.4412 Na, 1.4437 Tl, $N_g - N_p = 0.0114$ Na. Colorless. Made from H_2O solution above 30° C.

$Na_2HAsO_4 \cdot 7H_2O$ is monoclinic with $a : b : c = 1.229 : 1 : 1.353$, $\beta = 82° 46'$. Crystals thick basal plates or prismatic with 100 cleavage. G. = 1.88. The optic plane is normal to 010; $Z \wedge c = -65°$. (+) $2V = 57° 32'$ Li, $57° 7'$ Na, $56° 43'$ Tl, $\rho > v$ weak. $N_g = 1.4746$ Li, 1.4782 Na, 1.4814 Tl, $N_m = 1.4623$ Li, 1.4658 Na, 1.4689 Tl, $N_p = 1.4587$ Li, 1.4622 Na, 1.4654 Tl, $N_g - N_p = 0.016$ Na. Colorless. Made from H_2O solution above 20° C.

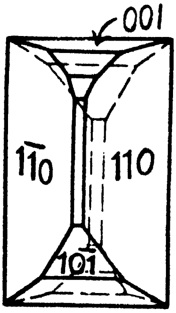

FIG. 254.—A crystal habit of $NH_4NaHPO_4 \cdot 4H_2O$. (After Groth.)

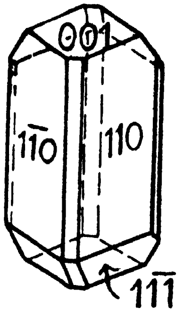

FIG. 255.—A crystal habit of $Na_2HPO_4 \cdot 12H_2O$. (After Groth.)

$Na_2HPO_4 \cdot 12H_4O$ is monoclinic with $a : b : c = 1.732 : 1 : 1.416$, $\beta = 58° 36'$. Crystals prismatic, as in Fig. 255. G. = 1.53. The optic plane is 010; $X \wedge c = -31°$, distinct dispersion. (−) $2V = 54° 38'$ Li, $56° 43'$ Na, $58° 9'$ Tl, $\rho < v$ marked. $N_g = 1.4341$ Li, 1.4373 Na, 1.4402 Tl, $N_m = 1.4330$ Li, 1.4361 Na, 1.4389 Tl, $N_p = 1.4290$ Li, 1.4321 Na, 1.4348 Tl, $N_g - N_p = 0.0052$ Na. Colorless.

$Na_2HAsO_4 \cdot 12H_2O$ is monoclinic with $a : b : c = 1.75 : 1 : 1.412$, $\beta = 58° 11'$. Crystals prismatic. G. = 1.67. The optic plane is normal to 010; $X \wedge c = -1°$. (−) $2V = 65° 13'$. $N_g = 1.4480$ Li, 1.4513 Na, 1.4545 Tl, $N_m = 1.4462$ Li, 1.4496 Na, 1.4527 Tl, $N_p = 1.4420$ Li, 1.4453 Na, 1.4482 Tl, $N_g - N_p = 0.006$ Na. Colorless.

3. ANHYDROUS ACID AND NORMAL PHOSPHATES, ETC., OF DIVALENT BASES

$Pb_3(PO_4)_2$ is hexagonal;[3] crystals prismatic. F. = 1015° C. Uniaxial negative with N_o = 1.9588 C, 1.9702 D, 1.9994 F, N_e = 1.9269 C, 1.9364 D, 1.9618 F, $N_o - N_e$ = 0.0338 D. Colorless. Made from fusion.

$Pb_3(PO_4)_2$ with 2 per cent $CePO_4$ is hexagonal.[3] Uniaxial negative with N_o = 1.9587 C, 1.9690 D, 1.9999 F, N_e = 1.9227 C, 1.9322 D, 1.9600 F, $N_o - N_e$ = 0.0368 D. With 3 per cent $CePO_4$ crystals are golden yellow with X = colorless, Z = canary yellow. N_o = 1.9586 C, 1.9697 D, 1.9995 F, N_e = 1.9221 C, 1.9326 D, 1.9591 F, $N_o - N_e$ = 0.0371 D. Made from fusion.

$SrHPO_4$ is orthorhombic with $a : b : c = 0.648 : 1 : 0.858$. Crystals thin 100 plates. G. = 3.54. The optic plane is 100. N_g = 1.625,[4] N_m = ?, N_p = 1.608, $N_g - N_p$ = 0.017. Colorless. Made from solution above 150° C.

$BaHPO_4$ is orthorhombic with $a : b : c = 0.713 : 1 : 0.812$. Crystals short prisms. G. = 4.16. The optic plane is 100. N_g = 1.635,[4] N_m = ?, N_p = 1.617, $N_g - N_p$ = 0.018. Colorless. Made from solution.

$PbHAsO_4$ is monoclinic with $a : b : c = 0.864 : 1 : 0.718$, β = 84° 36′. Crystals 010 plates with distinct 010 cleavage. H. = 2.5. G. = 5.8. The optic plane and X are normal to 010; $Y \wedge c = +38°$,[5] $-24°$.[6] (+) 2V = 58°, N_g = 1.9765 Na, N_m = 1.9097, N_p = 1.8903, $N_g - N_p$ = 0.0862 (nat. cryst.).[5] Colorless. Made by dissolving the precipitate formed when sodium arsenate is added to lead nitrate solution in nitric acid and slowly reprecipitating with warm ammonia. The natural substance,[6] called *schultenite*, has been found in Africa.

$CaHPO_4$ is triclinic with $a : b : c = 0.647 : 1 : 0.824$, α = 84° 57′, β = 90° 17′, γ = 94° 22′. Crystals thin 010 plates or $10\bar{1}$ plates elongated parallel to the edge $10\bar{1}$: 011. H. = 3.5, G. = 2.92, F. = 3. Soluble in acid. An extinction direction in 100 at 30° to 010, in 010 at 23° to 101, and in $10\bar{1}$ nearly parallel to 011 (elongation). N_g = 1.63,[4] N_m = ?, N_p = 1.61, $N_g - N_p$ = 0.02. Colorless. Made from solution above 50° C. The natural substance called *monetite*,[7] occurs in limestone beneath guano in the West Indies.

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[3] F. Zambonini: *Bull. Soc. Fr. Min.*, XXXVIII, 1915, p. 206.

[4] Paul Gaubert: *C. R. Cong. Sav. Soc. Sci.*, 1925; *Bull. Soc. Fr. Min.*, L, 1927, p. 504.

[5] A. de Schulten: *Bull. Soc. Fr. Min.*, XXVII, 1904, p. 120.

[6] L. J. Spencer: *Mineral. Mag.*, XXI, 1926, p. 149.

$SrHAsO_4$ is triclinic with $a : b : c = 0.647 : 1 : 0.835$, $\alpha = 86° 32'$, $\beta = 90° 46'$, $\gamma = 92° 4'$. Crystals elongated parallel to b. G. = 4.03. An extinction direction in 100 is at 14° to b in the obtuse angle α. $N_g = 1.67$,[4] $N_m = ?$, $N_p = 1.65$, $N_g - N_p = 0.02$. Colorless. Made from solution.

$H_4Pb(AsO_4)_2$ is triclinic;[8] crystals rhomboidal plates with angle of 68°. G. = 4.46. (−?) 2V = ? $N_g = ?$, $N_m = 1.82$, $N_p = 1.74$, $N_g - N_p > 0.08$. Extinction at 8° to a long edge.

4. ANHYDROUS BASIC (OR HALOGEN-CONTAINING) PHOSPHATES, ETC., OF DIVALENT BASES

$Sr_5ClP_3O_{12}$ is hexagonal[9] with G. = 4.87. F. = 1625° C. Uniaxial positive with $N_o = 1.650$, $N_e = 1.655$, $N_e - N_o = 0.005$; also[3] $N_o = 1.658$, $N_e = 1.664$, $N_e - N_o = 0.006$. Colorless.

$Sr_5FP_3O_{12}$ is hexagonal[9] with F. = 1685° C. Uniaxial negative with $N_o = 1.621$, $N_e = 1.619$, $N_o - N_e = 0.002$. Colorless.

$Ba_5ClP_3O_{12}$ is hexagonal[9] with G. = 5.95. F. = 1584° C. Uniaxial negative with $N_o = 1.701$, $N_e = 1.699$, $N_o - N_e = 0.002$. Colorless.

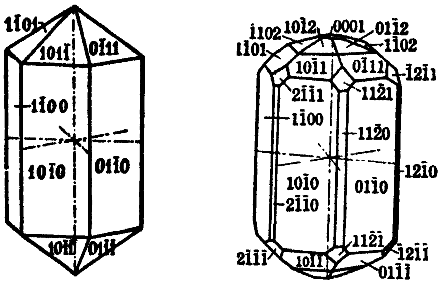

FIG. 256. FIG. 257.

FIGS. 256, 257.—Crystal habits of $Ca_5F(PO_4)_3$ (apatite).

$Ba_5FP_3O_{12}$ is hexagonal[9] with F. = 1670° C. Uniaxial negative with $N_o = 1.669$, $N_e = 1.665$, $N_o - N_e = 0.004$. Colorless.

$Ca_5FP_3O_{12}$ is hexagonal with $c = 0.735$. Crystals long to short prismatic with G. = 3.2. F. = 5. Soluble in HCl or HNO_3. Uniaxial negative[10] with $N_o = 1.6325$, $N_e = 1.629\pm$, $N_o - N_e = 0.003\pm$

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[7] Gaubert suggests that the indices measured by Larsen for monetite were made actually on gypsum.

[8] C. C. McDonnell and C. M. Smith; *Jour. Am. Chem. Soc.*, XXXVIII, 1916, p. 2027; also *Inter. Crit. Tables*, I, 1926, p. 116.

[9] H. Winter: *Inaug. Diss. Leipzig*, 1913; *Tables Ann. Int. Const.*, IV, 1922, p. 1063, 1067.

[10] R. Nacken: *Cent. Mineral.*, 1912, p. 546; F. Zambonini: *Zeit. Kryst.*, LVII, 1923, p. 271.

Colorless. Made from fusion. The natural substance, called *fluorapatite*, is not rare.

$Ca_5ClP_3O_{12}$ is hexagonal with $c = 0.735$. Crystals prismatic. Uniaxial negative with $N_o = 1.6642$ B, 1.6668 D, 1.6747 F, $N_o - N_e = 0.0006$ to 0.0010. Also[4] $N_o = 1.642$, $N_e = 1.637$, $N_o - N_e = 0.005$. Colorless. Made from fusion. Forms a series with $Ca_5FP_3O_{12}$. Artificial $Ca_3(PO_4)_2$: $CaCl_2 = 4.34 : 1$ has $N_o - N_e = 0.0050$ to 0.0058. The natural substance, called *chlorapatite*, is uncommon.

$Pb_5ClAs_3O_{12}$ is hexagonal with $c = 0.725$. Crystals prismatic. H. = 3.5. G. = 7.15. F. = 1. Soluble in HNO_3. Uniaxial negative[11] with $N_o = 2.16$, $N_e = 2.13$, $N_o - N_e = 0.03$. Colorless.

Ca_2ClPO_4 is orthorhombic[12] in oblong plates with good 001 cleavage. G. = 3.17. The optic plane is 010; $Z = c$. (+) 2V = large. $N_g = 1.670$, $N_m = 1.665$ (1.658 Nacken)[13], $N_p = 1.649$, $N_g - N_p = 0.021$. Colorless.

$Zn_2(OH)PO_4$ is orthorhombic[14] (?). The optic plane is 010 and $X = a$. (−) 2V = large. $N_g = 1.629$, $N_m = 1.624$, $N_p = 1.608$, $N_g - N_p = 0.021$. Colorless to brownish. Produced by dehydration of spencerite.

$Cu_2(OH)PO_4$ is orthorhombic[15] with $N_m = 1.743$.

$Zn_4P_2O_9$ is orthorhombic (?). The optic plane is normal to 010; $X = a$. (−) 2V = 25°–35°. $N_g = 1.660$, $N_m = 1.656$, $N_p = 1.630$, $N_g - N_p = 0.030$. Color brown (due to air films in the cleavages?). Produced by dehydration of spencerite.

$Ca_4P_2O_9$ is monoclinic with $a : b : c = 0.577 : 1 : 1.255$, $\beta = 90° \pm$. Crystals 010 tablets with imperfect 010, 100 and 001 cleavages. G. = 3.06. Lamellar twinning on 001 and on 100. The optic plane is 010; $Z = c$ nearly. (+) 2V = 20° (red), 40° (blue). $N_m = 1.64$, $N_g - N_p$ = rather strong. Colorless. Common in Thomas slags.

5. ANHYDROUS PHOSPHATES, ETC., OF TRIVALENT BASES

$FeAsO_4$ is monoclinic with $a : b : c = 0.616 : 1 : 0.322$, $\beta = 77° 8'$. Crystals prismatic, vertically striated, with distinct 001 cleavage. H. = 5. G. = 4.32. F. = easy. Slowly soluble in acid. Extinction on 010 at +53° from *c*. N = 1.78. Color black to brown; strongly pleochroic with *a* = greenish yellow, *b* = dark brownish yellow as seen in 001, and olive brown to clear yellowish brown as seen in 010.

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[11] C. C. McDonnell and C. M. Smith: *Amer. Jour. Sci.*, CXCII, 1916, p. 139.

[12] F. K. Cameron and W. J. McCaughey: *Jour. Phys. Chem.*, XV, p. 463.

[13] R. Nacken: *Cent. Mineral.*, 1912, p. 551.

[14] T. L. Walker and A. L. Parsons: *Univ. Toronto Studies, Geol. Ser.*, No. 12, 1921, p. 58.

[15] *Int. Crit. Tables*, I, 1926, p. 123.

6. HYDROUS PHOSPHATES, ETC., CONTAINING TETRAVALENT OR HEXAVALENT BASES

$Cu(UO_2)_2P_2O_8 \cdot 12H_2O$ is orthorhombic and pseudotetragonal with $c = 2.97$ and perfect 001 and distinct 100 cleavages. H. = 2–2.5. G. = 3.22. F. = 2.5. Soluble in HNO_3. (−) 2V = very small, $N_g = 1.592$, $N_m = 1.592$, $N_p = 1.582$, $N_g - N_p = 0.010$. Color green with X = pale green or pale blue, Y = Z = greenish yellow and X < Y = Z. The natural substance, called *torbernite*, is found in veins, etc. By dehydration at about 65° C. to " $8H_2O$ " it is pseudotetragonal with $c = 2.28$. G. = 3.68. Nearly uniaxial and positive[16] in red and yellow light, isotropic in green light and negative in blue light. The interference colors are quite abnormal, being confined to red and blue. $N_o = 1.624$ Na (1.610 to 1.628), $N_e = 1.626$, $N_e - N_o = 0.002$. Color green with X = pale blue, Z = green. The natural substance, called *metatorbernite*, is found in Cornwall, etc. On further heating[17] the substance loses one H_2O at about 95° C., four more at about 150 C., two more at about 225° C., and the last one at red heat. Above 100° C. the substance is clearly orthorhombic with twinning on 110; it finally turns brown and becomes decidedly biaxial (negative) with X = *c* and Z = *a*; an intermediate stage has a smaller optic angle about X with X = *c* and Z = *b*. The water is lost only through vertical faces and not through the base.[18]

$Ca(UO_2)_2P_2O_8 \cdot 12H_2O$ is orthorhombic and pseudotetragonal with perfect 001 and distinct 100 and 010 cleavages. G. = 2.50. The optic plane is 010; X = *c*. (−) 2V = 69°, $N_g = 1.521$, $N_m = 1.510$, $N_p = 1.488$ (calc.), $N_g - N_p = 0.033$. Color yellow with X = pale yellow, Y and Z = deep yellow. The natural substance, perhaps *uranospathite*,[19] is found in Cornwall. By dehydration to about " $8H_2O$," the substance is still orthorhombic with $a : b : c = 0.988 : 1 : 2.852$ and pseudotetragonal with perfect 001 and distinct 100, 010 and 110 cleavages. Twinning on 110. H. = 2–2.5. G. = 3.10. F. = 3.

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[16] N. L. Bowen: *Am. Jour. Sci.*, CXCVIII, 1919, p. 195.

[17] F. Rinne: *Cent. Min.*, 1901, p. 623; Buchholz; *Cent. Min.*, 1903, p. 363.

[18] A. F. Hallimond: *Mineral. Mag.*, XVII, 1916, p. 326; XIX, 1920, p. 43.

[19] A. F. Hallimond: *Mineral. Mag.*, XVII, 1915, p. 221.

Soluble in HNO_3. The optic plane is still 010 with $X = c$. (−) $2V = 33°$, $N_g = 1.577$, $N_m = 1.575$, $N_p = 1.553$, $N_g - N_p = 0.024$. Another measure [20] gave (−) $2E = 45°$, $N_m = 1.596$. Also uniaxial negative [21] with $N_o = 1.598$, $N_e = 1.586$, $N_o - N_e = 0.014$. With about $7H_2O$, $N_o = 1.600$, $N_e = 1.590$, $N_o - N_e = 0.010$. Some crystals weakly birefringent in basal plates (with a gray-blue interference color) and therefore biaxial. Color yellow with $X < Z$. In a desiccator the substance may become uniaxial. A natural substance called *autunite* is probably the same. A monoclinic mineral (of the same composition?) has been described as *bassetite*.[19] In a desiccator the extinction angle ($Z \wedge c$) in bassetite increases from − 4° to 20°. By exchange of bases between artificial autunite and salts in solutions in which the mineral is placed the calcium may be replaced [21] by sodium, potassium, barium, manganese, copper, lead or magnesium. This exchange is controlled by valence in all cases, but under suitable conditions another sodium compound can be produced in which atom-for-atom replacement of calcium by sodium may have occurred. Also P_2O_5 in autunite can probably be replaced by As_2O_5, V_2O_5, etc., quite easily. The tenor of water in these minerals varies very easily depending upon vapor pressure and temperature. The following compounds [21] have been made and measured optically:

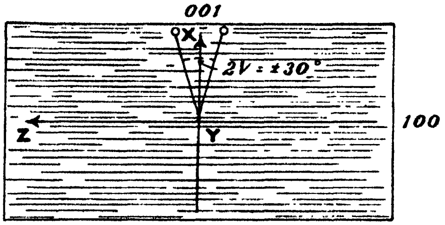

FIG. 258.—Optic orientation of $Ca(UO_2)_2(PO_4)_2 \cdot 8H_2O$ (autunite).

$Na_2(UO_2)_2P_2O_8 \cdot 6.5H_2O$ is nearly uniaxial and negative with $N_g = 1.582$, N_m nearly $= N_g$, $N_p = 1.562$, $N_g - N_p = 0.020$.

$NaH(UO_2)_2P_2O_8 \cdot 7.3H_2O$ is nearly uniaxial and negative with $N_o = 1.580\pm$, $N_e = ?$, $N_o - N_e$ = moderate.

$Na_2(UO_2)_2P_2O_8 \cdot 6.5H_2O$ with $2CaO : Na_2O = 1 : 9$ is uniaxial negative with $N_o = 1.584$,[22] $N_e = ?$, $N_o - N_e$ = moderate.

$K_2(UO_2)_2P_2O_8 \cdot nH_2O$ is negative and uniaxial or biaxial; the crystals are not rectangular in outline, but have an angle of 82° instead of 90°—perhaps monoclinic. They show fine rectangular lamellar twinning like microcline. Biaxial crystals have a small optic angle.

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[20] B. Stoces: *Mineral. Abst.*, I, 1922, p. 291.

[21] J. G. Fairchild and W. T. Schaller: *Am. Mineral.*, XIV, 1929, p. 265.

[22] Correction of published value—see *Am. Mineral.*, XIV, 1929, p. 490.

$N_g = 1.575$, N_m nearly $= N_g$, $N_p = 1.553$, $N_g - N_p = 0.022$. [Apparently these crystals were produced by solution and redeposition rather than by base exchange.—A.N.W.]

$Ba(UO_2)_2P_2O_8 \cdot 6.1H_2O$ is pseudotetragonal and negative, most of the crystals being uniaxial. Broad lamellar twinning on both 100 and 110. $N_o = 1.613$, $N_e = 1.604$, $N_o - N_e = 0.009$.

$Mn(UO_2)_2P_2O_8 \cdot 7.6H_2O$ is tetragonal to pseudotetragonal with weak to moderate birefringence in basal plates and lamellar twinning on 110; some plates show the " ultra blue " interference color due to dispersion. $N_o = 1.598$ to 1.601, $N_e = ?$, $N_o - N_e =$ weak to moderate.

$Cu(UO_2)_2P_2O_8 \cdot 10.6H_2O$ is pseudotetragonal; nearly uniaxial and negative with $N_o = 1.608$, $N_e = ?$. Color deep green. This is probably the same as the natural mineral known as *torbernite* (partly dehydrated), in which $N_o = 1.592$, $N_e = 1.582$, $N_o - N_e = 0.010$ and $X < Z$.

$Pb(UO_2)_2P_2O_8 \cdot 8.4H_2O$ is pseudotetragonal in 8-sided basal plates or less regular flakes. Basal plates are very weakly birefringent. $N_g = 1.625 — 1.627$, N_m nearly $= N_g$, $N_p = ?$, $N_g - N_p = ?$.

$Mg(UO_2)_2P_2O_8 \cdot 8.1H_2O$ is pseudotetragonal; basal plates isotropic or weakly birefringent. $N_o = 1.58\pm$, $N_e = ?$, $N_o - N_e = ?$. Nearly colorless.

7. METAPHOSPHATES, ETC.

NH_4PO_3 is monoclinic;[23] crystals platy with G. = 2.21. Biaxial positive of large optic angle with $N_g = 1.505$, $N_m = ?$, $N_p = 1.490$, $N_g - N_p = 0.015$. Colorless. Made by reaction of $(NH_4)_2S$ and $Pb(PO_3)_2$ and precipitation with alcohol.

$NaPO_3$ is apparently monoclinic.[24] It is biaxial negative of large optic angle with $N_g = 1.486$, $N_m = ?$, $N_p = 1.473$, $N_g - N_p = 0.113$. Colorless. Made by dehydrating $NaH_2PO_4 \cdot 2H_2O$ in an electric furnace.

$CaV_2O_6 \cdot 4H_2O$ is triclinic[25] with $\alpha = 98° 18'$, $\beta = 97° 24'$, $\gamma = 89° 34'$; crystals prismatic with distinct 010 cleavage. H. = 2–3. G. = 2.45. $Z = c\pm$; extinction on 001 at 16° to 010. (+) $2V =$ large, with very strong dispersion. $N_g = 1.840$, $N_m = 1.770$, $N_p = 1.710$, $N_g - N_p = 0.130$. Color yellow. The natural substance, called *rossite*, was found in a vein in Colorado.

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[23] R. J. Colony: *Jour. Am. Chem. Soc.*, XLIX, 1927, p. 123.

[24] R. J. Colony: *Jour. Amer. Chem. Soc.*, XLIX, 1927, p. 1880.

[25] W. F. Foshag and F. L. Hess: *U. S. Nat. Mus. Proc.*, LXXII, 1927, Art. 11.

8. PHOSPHITES, ETC.

$Na_2HPO_3 \cdot 5H_2O$ is orthorhombic with $a : b : c = 0.70 : 1 : 0.78$. Crystals prismatic. The optic plane is 001; Z = *a*. (+) 2V = 44°. $N_m = 1.4434$, $N_g - N_p$ = weak. Colorless.

$NaH_2PO_3 \cdot 2.5H_2O$ is monoclinic with $a : b : c = 1.202 : 1 : 0.796$, $\beta = 80° 7'$. Crystals thick 001 tablets. The optic plane is 010; $Z \wedge c = -54° 33'$. (+) 2V = 77° 36′ Li, 77° 38′ Na, 77° 40′ Tl, $\rho < v$ very weak. $N_g = 1.4493$ Na, $N_m = 1.4281$ Li, 1.4309 Na, 1.4334 Tl, $N_p = 1.4193$ Na, $N_g - N_p = 0.030$. Colorless.

9. HYPOPHOSPHATES

$K_2H_2P_2O_6 \cdot 3H_2O$ is orthorhombic with $a : b : c = 0.992 : 1 : 0.901$. Crystals vertical columnar with 100, 010, 110, 101, 103, etc. The optic plane is 100; X = *c*. (−) 2V = 62°, $\rho < v$ very weak. $N_g = 1.4870$ Na, $N_m = 1.4843$, $N_p = 1.4768$, $N_g - N_p = 0.0102$. Colorless.

$K_2H_2P_2O_6 \cdot 2H_2O$ is monoclinic with $a : b : c = 0.745 : 1 : 0.798$, $\beta = 81° 31'$. Crystals 001 tablets bounded by 110, 221, etc. The optic plane is normal to 010; $X \wedge c = -36° 30'$. (−) 2V = 36° 9′ Na, $\rho < v$, very weak. $N_g = 1.5363$ Na, $N_m = 1.5314$, $N_p = 1.4893$, $N_g - N_p = 0.049$. Colorless.

$Na_2H_2P_2O_6 \cdot 6H_2O$ is monoclinic with $a : b : c = 2.013 : 1 : 2.038$, $\beta = 53° 13'$. Crystals basal tablets or short prisms. Perfect 001 and imperfect 110 cleavages. Twinning on $10\bar{1}$. G. = 1.85. The optic plane is 010; $Z \wedge c = +35° 17'$ Na. (+) 2V = 55° 36′ Li, 57° 20′ Na, 58° 10′ Tl. $N_g = 1.5006$ Li, 1.5041 Na, 1.5074 Tl, $N_m = 1.4861$ Li, 1.4897 Na, 1.4927 Tl, $N_p = 1.4882$ Li, 1.4855 Na, 1.4883 Tl, $N_g - N_p = 0.0186$ Na. Colorless. Made by cooling a saturated solution.

$HNa_3P_2O_6 \cdot 9H_2O$ is monoclinic with $a : b : c = 1.552 : 1 : 1.510$, $\beta = 77° 58'$. Crystals basal tablets bounded by 101, 034, 110, etc. Twinning on axis *a*. G. = 1.74. The optic plane is normal to 010, $X \wedge c = -10°$ Li, $-11°$ Na, $-12°$ Tl. (−) 2V = 82° 2′ Li, 82° 0′ Na, 81° 56′ Tl, $\rho > v$, very weak. $N_g = 1.4769$ Li, 1.4804 Na, 1.4836 Tl, $N_m = 1.4705$ Li, 1.4738 Na, 1.4769 Tl, $N_p = 1.4622$ Li, 1.4653 Na, 1.4682 Tl, $N_g - N_p = 0.0182$ Na. Colorless.

$Na_4P_2O_6 \cdot 10H_2O$ is monoclinic with $a : b : c = 1.172 : 1 : 1.908$, $\beta = 79° 44'$. Crystals domatic, terminated by prisms, etc. Lamellar twinning on 001; 010 and 101 cleavages. G. = 1.82. The optic plane is 010; $Z \wedge c = -39\frac{1}{2}°$. (+) 2V = 48° 58′ Li, 48° 56′ Na, 48° 43′ Tl,

$\rho > v$ very weak. $N_g = 1.5036$ Na, $N_m = 1.4789$ Li, 1.4822 Na, 1.4852 Tl, $N_p = 1.4777$ Na, $N_g - N_p = 0.0259$ Na. Colorless.

10. PYROPHOSPHATES, PYROANTIMONATES

$Mg_2P_2O_7$ is monoclinic [26] with $a : b : c = 0.795 : 1 : 1.088$, $\beta = 75°\ 49'$. Crystals rude basal tablets, with perfect 110 and good 001 cleavages. H. = 4. G. = 3.06. Fuses at 1383° C. The optic plane is 010; $X \wedge c = +15°$ (X nearly normal to 001). (+) $2V = 20\frac{1}{2}°$. $N_g = 1.615$ Na, $N_m = 1.604$, $N_p = 1.602$, $N_g - N_p = 0.013$. Colorless. Made from fusion.

$Mn_2P_2O_7$ is monoclinic [26] with $a : b : c = 0.783 : 1 : ?$, $\beta = 74°\ 9'$. Crystals prismatic with perfect 110 and poor 001 cleavages. H. = 4. G. = 3.71. Fuses at 1196° C. The optic plane is 010; $X \wedge c = -4°$. (+) 2V nearly 90°. $N_g = 1.710$ Na, $N_m = 1.704$ (?), $N_p = 1.695$, $N_g - N_p = 0.015$. Color brownish pink with X = light pink, Y and Z = nearly colorless to very pale yellow in thick plates. Miscible in all proportions with $Mg_2P_2O_7$ with no eutectic, but optic data are meager. Made from fusion.

$Pb_2As_2O_7$ is biaxial [27] with G. = 6.85, F. = 802° C. and $N_m = 2.03$ D.

$Ca_2P_2O_7$ is biaxial [28] in squarish to fibrous crystals. (−) 2V = small to moderate. $N_g = 1.605$, $N_m = 1.60\pm$, $N_p = 1.585$, $N_g - N_p = 0.020$. Colorless.

$Na_2H_2P_2O_7 \cdot 6H_2O$ is monoclinic with $a : b : c = 2.026 : 1 : 2.049$, $\beta = 56°\ 41'$. Crystals 001 tablets with perfect 001 cleavage. G. = 1.86. The optic plane is normal to 010; $X \wedge c = -42\frac{1}{2}°$. (−) $2V = 15°\ 13'$ Li, $31°\ 56'$ Na, $36°\ 10'$ Tl. $N_g = 1.4617$ Li, 1.4649 Na, 1.4677 Tl, $N_m = 1.4616$ Li, 1.4645 Na, 1.4672 Tl, $N_p = 1.4573$ Li, 1.4599 Na, 1.4623 Tl, $N_g - N_p = 0.005$ Na. Colorless. Made by adding acetic acid to a warm solution of the normal salt.

$Na_4P_2O_7 \cdot 10H_2O$ is monoclinic with $a : b : c = 1.287 : 1 : 1.895$, $\beta = 81°\ 44'$. Crystals domatic. G. = 1.82. The optic plane is normal to 010; Z nearly exactly normal to 101. (+) $2V = 60\frac{1}{2}°$. $N_g = 1.4575$ Li, 1.4604 Na, 1.4629 Tl, $N_m = 1.4496$ Li, 1.4525 Na, 1.4551 Tl, $N_p = 1.4470$ Li, 1.4499 Na, 1.4526 Tl, $N_g - N_p = 0.0104$ Na. Colorless. Made from solution.

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[26] O. Andersen: *Jour. Wash. Acad. Sci.*, IV, 1914, p. 318.

[27] *Int. Crit. Tables*, I, 1926, p. 115.

[28] H. E. Merwin: *Am. Jour. Sci.*, CCIX, 1925, p. 252.

11. PHOSPHATES, ETC., WITH SALTS OF OTHER OXYGEN ACIDS

$3Ca_3P_2O_8 \cdot CaCO_3$ is hexagonal like apatite. Uniaxial negative[29] with $N_o = 1.635$, $N_e = 1.626$, $N_o - N_e = 0.009$. Colorless.

$3Sr_3P_2O_8 \cdot SrCO_3$ is hexagonal;[29] uniaxial negative with $N_o = 1.644$, $N_e = 1.638$, $N_o - N_e = 0.006$. Colorless.

$3Ba_3P_2O_8 \cdot BaCO_3$ is hexagonal;[29] uniaxial negative with $N_o = 1.691$, $N_e = 1.683$, $N_o - N_e = 0.008$. Colorless.

X. COLUMBATES, TANTALATES, TITANATES AND ZIRCONATES

$K_2Ti_2O_5$ is orthorhombic[1] and acicular with good pinacoidal cleavage (001) parallel to elongation and two other less distinct pinacoidal cleavages. Optic plane normal to elongation. (−) 2V = rather large. N = more than 1.74, $N_g - N_p$ = strong. Made by fusion of K_2CO_3 and TiO_2.

$Na_2Ti_2O_5$ (?) is orthorhombic;[1] like $K_2Si_2O_5$ in cleavages, form and optic orientation. X normal to best cleavage (001) and Y parallel to elongation. (−) 2V = moderate. N = high, $N_g - N_p$ = strong. Made by fusion of Na_2CO_3 and TiO_2.

Na_2ZrO_3 is probably orthorhombic[2] showing common pseudohexagonal twinning. G. = 4.0. (−) 2V = ?, N_g distinctly above 1.8, N_m = ?, $N_p = 1.720$, $N_g - N_p > 0.08$. Colorless. Formed from fusion. Fuses incongruently at about 1500° C.

$Na_8Ti_5O_{14}$ is probably monoclinic;[1] granular with many faces; angles of 117° and 130° common. (−) 2V = moderate or large. $N > 1.74$, $N_g - N_p$ = strong. Made by fusion of Na_2CO_3 and TiO_2.

$Na_4Si_4Ti_5O_{20}$, made by Hautefeuille in flattened prisms, has[3] G. = 2.88 and $N_g = 1.655$, N_m = ?, $N_p = 1.623$, $N_g - N_p = 0.032$.

XI. SILICATES

Titanosilicates, zirconosilicates, thorosilicates and stannosilicates as well as alumosilicates and borosilicates are included with ordinary silicates in this division. The classification of the silicates is still unsatisfactory because the members of a single isomorphous group may include two (or more) types of silicic acid and varying numbers of atoms of bases of varying valence. Recent X-ray work, which may lead to a new classification of silicates, suggests that silicates are not salts of any silicic acid, since forsterite, for example, is not composed of Mg atoms and SiO_4 groups but of MgO groups and SiO_2 groups. The following classification may serve for the present occasion:

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[29] W. Eitel: *Zeit. Kryst.*, LXI, 1925, p. 594.

[1] P. Niggli: *Zeit. anorg. Chem.*, XCVIII, 1916. p. 241.

[2] *Zeit. anorg. Chem.*, CXCI, 1930, p. 1.

[3] P. Gaubert: *Bull. Soc. Fr. Min.*, L, 1927, p. 504.

1. Zirconosilicates of monovalent bases.
2. Silicates of monovalent bases without hydrogen.
3. Silicates of monovalent bases with hydrogen.
4. Anhydrous silicates of divalent bases.
5. Hydrous silicates of divalent bases.
6. Anhydrous silicates of trivalent bases.
7. Hydrous silicates of trivalent bases.
8. Anhydrous silicates of divalent and monovalent bases.
9. Anhydrous silicates of trivalent and monovalent bases.
10. Hydrous silicates of trivalent and monovalent bases.
11. Anhydrous silicates of trivalent and divalent bases.
12. Hydrous silicates of trivalent and divalent bases (with or without monovalent bases).
13. Compounds consisting of silicates with salts of other oxygen acids.
14. Siliceous glasses.

1. ZIRCONOSILICATES OF MONOVALENT BASES

$Na_4Zr_2Si_3O_{12}$ is trigonal[1] with rhombohedral habit. G. = 2.88. Fuses at 1540° C. Uniaxial negative with $N_o = 1.715$ Na, $N_e = 1.692$, $N_o - N_e = 0.023$. Colorless.

Na_2ZrSiO_5 is orthorhombic[1] often in pseudohexagonal twins of prismatic form with positive elongation. G. = 3.605. Fuses incongruently at 1477° C. (−) 2V = small. $N_g = 1.790$ Na, N_m slightly less than 1.790, $N_p = 1.741$, $N_g - N_p = 0.049$. Colorless.

$Na_2ZrSi_2O_7$ forms long needles,[1] perhaps monoclinic, with a very small extinction angle. $N_g = 1.710$, $N_m = ?$, $N_p = 1.688$, $N_g - N_p = 0.022$. Colorless.

2. SILICATES OF MONOVALENT BASES WITHOUT HYDROGEN

Li_2SiO_3 is trigonal[2] (?) with $c = 0.668$; cleavage parallel to elongation of needles. Crystals of variable habit. G. = 2.52. F. = 1202°

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[1] *Zeit. anorg. Chem.*, CXCI, 1930, p. 1.

[2] *Jour. Wash. Acad. Sci.*, I, 1911, p. 49.

C. Uniaxial (or biaxial – Jaeger)[3] positive with $N_o = 1.591$, $N_e = 1.611$, $N_e - N_o = 0.020$ (Merwin[3a]); $N_o = 1.584$, $N_e = 1.609$, $N_e - N_o = 0.025$ (Jaeger).[3] Colorless. Made from fusion. Fused Li_2SiO_3 as glass has G. = 2.35, N = 1.548 Na.

Li_4SiO_4 is pseudohexagonal,[4] probably orthorhombic; lamellar twinning common, rarely in two sets. G. = 2.39. Decomposes at 1255°. Large extinction angle on twinning. (+) 2V = very small. $N_g = 1.610 \pm 0.002$, $N_m = ?$, $N_p = 1.602 \pm 0.002$ (Merwin[3a]), $N_g = 1.61\pm$, $N_m = 1.60\pm$, $N_g - N_p$ = moderate (Fenner), $N_g = 1.614$ Na, $N_m = ?$, $N_p = 1.594$, $N_g - N_p = 0.020$ (Jaeger).[3] Colorless. May be colored pink by Li_2O_2 or deep lilac by Ni if made in a nickel crucible; then pleochroic. Made from fusion.

$Li_2Si_2O_5$ is orthorhombic[3] (?). Crystals tabular and rectangular with three rectangular cleavage directions, one being micaceous and the others nearly perfect. G. = 2.454. F. = 1032° C. (incongruently). The optic plane is parallel to the micaceous cleavage and Z is parallel to the two best cleavages according to Merwin.[3a] (+) 2V = 50°–60°, $N_g = 1.558$, $N_m = 1.550$, $N_p = 1.547$, $N_g - N_p = 0.011$, all ± 0.001 (Merwin[3a]). $N_g = 1.545$, $N_m = ?$, $N_p = 1.525$, $N_g - N_p = 0.020$ (Jaeger[3]). Colorless. Made from fusion.

Na_2SiO_3 is orthorhombic[5] and prismatic with distinct prismatic cleavages. F. = 1088° C. Hydrates easily. Elongation is positive and extinction parallel. (–) 2V = very large. $N_g = 1.528$, $N_m = 1.520$, $N_p = 1.513$, $N_g - N_p = 0.015\pm$. Colorless. Made from fusion.

Na_4SiO_4 has two crystal phases; the low temperature phase[5] forms acute-angled plates (010?) with extinction at about –15° with the short edge. G. = 2.5. (–) 2V = ?, N = $1.536\pm$, $N_g - N_p$ = rather weak. Colorless. Inverts at 960° C. to the high temperature phase which is biaxial (?) with lamellar twinning;[6] it decomposes at 1089° C.; Z is nearly normal to the twinning lines and extinction varies up to 8° with the twinning plane. $N_g = 1.537$, $N_m = ?$, $N_p = 1.524$, $N_g - N_p = 0.013$. Colorless.

$Na_2Si_2O_5$ is orthorhombic[5] in 100 plates with perfect 100 and distinct 010 cleavages. Inverts reversibly at 678° C. and melts at 874° C. The optic plane is 010; $X = a$. (−) $2V = 50°–55°$. $N_g = 1.518$, $N_m = 1.514$, $N_p = 1.504$. Later measures by N. L. Bowen[6] gave $N_g = 1.508$, $N_m = 1.505$, $N_p = 1.497$, $N_g - N_p = 0.011$. Colorless. Made from fusion.

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[3] *Proc. K. Akad. Wet. Amst.*, XVI, 1914, p. 857.

[3a] *Jour. Phys. Chem.*, XXXIV, 1930, p. 2647.

[4] P. Niggli: *Zeit. anorg. Chem.*, LXXXIV, 1913, p. 229.

[5] G. W. Morey and C. N. Fenner: *Jour. Am. Chem. Soc.*, XXXVI, 1914, p. 215; *Zeit. anorg. Chem.*, LXXXVI, 1914, p. 305; G. W. Morey and N. L. Bowen: *Jour. Phys. Chem.*, XXVIII, 1924, p. 1167; *Trans. Soc. Glass Tech.*, IX, 1925, p. 226.

[6] F. C. Kracek: *Jour. Phys. Chem.*, XXXIV, 1930, p. 1583.

K_2SiO_3 is granular[7] with a cleavage parallel to Z; it is very hygroscopic and easily soluble in water.[7a] F. = 966° C. (+) $2V = 35°\pm$, $\rho < v$. $N_g = 1.528$, $N_m = 1.521\pm$, $N_p = 1.520$; $N_g - N_p = 0.008$. Colorless. Made from fusion.

$K_2Si_2O_5$ is orthorhombic;[7] six-sided plates have angles of about 40° and 80°; if these plates are parallel to 001, the cleavages are: 001 perfect; 010 distinct; 100 imperfect. Lamellar twinning nearly parallel to elongation *b*. Crystals from fusion elongated parallel to Z, from solution elongated parallel to Y. Crystals hygroscopic. F. = 1036° C. Optic plane is 010; $X = c$. (−) 2V = rather large. $N_g = 1.513$, $N_m = 1.509\pm$, $N_p = 1.503$, $N_g - N_p = 0.010$. Colorless. Made from fusion and from solution.

$K_2Si_4O_9$ forms plates[7] with twinning and inclined extinction, F. = 765° C. (+) 2V = large; $N_g = 1.482$, $N_m = ?$, $N_p = 1.477$, $N_g - N_p = 0.005$. Colorless.

$Na_6Si_2O_7$ forms small acute-angled plates[1] with distinct cleavage. G. = 2.96. Fuses at 1122° C. Biaxial (positive?). $N_g = 1.529$ Na, $N_m = ?$, $N_p = 1.524$, $N_g - N_p = 0.005$. Colorless. $Na_6Si_2O_7$ forms a glass with G. = 2.6.

3. SILICATES OF MONOVALENT BASES WITH HYDROGEN

$K_2SiO_3 \cdot \frac{1}{2}H_2O$ is probably orthorhombic[8] with good cleavage parallel to elongation, which is positive. Extinction parallel. (+?) 2V = very large. N estimated at 1.50, $N_g - N_p$ = strong. Easily soluble in water. Colorless. Made in a steel bomb.

$K_2SiO_3 \cdot H_2O$ is granular;[8] dissociates to form the preceding at 370° C.; altered by H_2O below 200° C. (+) 2V = small. N estimated at 1.50, $N_g - N_p$ = strong. Colorless. Made in a steel bomb.

$KHSi_2O_5$ is probably orthorhombic;[8] crystals prismatic, tabular. Altered by H_2O below 420°, but not at 0° C. 100 and 010 cleavages.

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[7] G. W. Morey and C. N. Fenner: *Jour. Am. Chem. Soc.*, XXXVI, 1914, p. 215, and XXXIX, 1917, p. 1173. Also F. C. Kracek, N. L. Bowen and G. W. Morey: *Jour. Phys. Chem.*, XXXIII, 1929, p. 1857.

[8] G. W. Morey and C. N. Fenner: *Jour. Am. Chem. Soc.*, XXXIX, 1917, p. 1173.

F. = 515° C. Optic plane is 001; Z = *a*. (+) 2E = 69½°; 2V = 40°±. N_g = 1.535, N_m = 1.530 (calc.), N_p = 1.495, $N_g - N_p$ = 0.040. Alters easily to N_g = 1.530, N_p = 1.480, $N_g - N_p$ = 0.050. Colorless. Made in a steel bomb.

$Na_2SiO_3 \cdot 9H_2O$ is orthorhombic[8a] with no distinct cleavage and variable crystal habit. The optic plane is 010: Z = *c*. (+?) 2V = 90°±, N_g = 1.460, N_m = 1.455+, N_p = 1.451, $N_g - N_p$ = 0.009. Colorless.

$3Na_2O \cdot 2SiO_2 \cdot 11H_2O$ (?) is orthorhombic[8a] of variable crystal habit. The optic plane is 010; X = *a*. (+) 2V = 65°±, N_g = 1.534, N_m = 1.510, N_p = 1.504, $N_g - N_p$ = 0.020. Colorless.

$Na_2SiO_3 \cdot 6H_2O$ is monoclinic[8a] with variable crystal habit. The optic plane and Z are normal to 010; $X \wedge c$ = 22°. (+) 2V = 75°±, N_g = 1.485, N_m = 1.473±, N_p = 1.465, $N_g - N_p$ = 0.020. Colorless.

$Na_2SiO_3 \cdot 8H_2O$ is monoclinic[8a] in crystals which are 001 tablets or prismatic. The optic plane is 010; $X \wedge c$ = 12°. (−) 2V = 63°, N_g = 1.465+, N_m = 1.463, N_p = 1.457+, $N_g - N_p$ = 0.008±. Dispersion (F–C) for N_m = 0.0090+. Colorless.

$K_2Si_2O_5 \cdot H_2O$ is granular;[8] dissociates at 405° C.; altered by H_2O below 280° C. (+) 2V = small. N estimated at 1.50, $N_g - N_p$ = strong. Colorless.

$Na_2SiO_3 \cdot 5H_2O$ is triclinic[8a] with undetermined optic orientation. (+) 2V = moderate, N_g = 1.467±, N_m = 1.454±, N_p = 1.447±, $N_g - N_p$ = 0.020±. Colorless.

4. ANHYDROUS SILICATES OF DIVALENT BASES

$Ca_2FeSi_2O_7$ is tetragonal with G. = 3.23. Uniaxial negative with N_o = 1.670, N_e = 1.658, $N_o - N_e$ = 0.012. Found in slags. *Justite* is a type in slags with about 50 per cent $Ca_2FeSi_2O_7$ and about 35 per cent $Ca_2(Zn,Mn)Si_2O_7$; it has N_o = 1.670, N_e = 1.657, $N_o - N_e$ = 0.013. Both belong to the *melilite* group.

$Ca_2MgSi_2O_7$ is tetragonal[9] with *c* = 0.45. Crystals short prisms or 001 tablets. H. = 5. G. = 3.18. F. = 1458° C. Gelatinizes with HCl. Uniaxial positive with N_o = 1.631, N_e = 1.638, $N_e - N_o$ = 0.007. Colorless. Made from fusion. This substance, as found in slags and in nature, is called ***akermanite*** and belongs to the ***melilite*** group. With about an equal amount of $Na_2Si_3O_7$ (?) it is uniaxial negative with $N_o = 1.632$, $N_e = 1.626$, $N_o - N_e = 0.006$. Colorless. Made from fusion. $Ca_2MgSi_2O_7$ glass has G. = 2.955 and N = 1.641 Na.

[8a] Salt prepared by G. W. Morey; properties measured by H. E. Merwin—personal communication, Mar. 25 and Apr. 2, 1931.

[9] J. B. Ferguson and H. E. Merwin: *Am. Jour. Sci.*, CXCVIII, 1919, p. 81; J. B. Ferguson and A. F. Buddington: *Am. Jour. Sci.*, CC, 1920, p. 131.

According to the author's interpretation[10] of the experimental work of Buddington[11] in the light of Berman's study,[12] $Ca_2MgSi_2O_7$ is difficultly miscible with $CaSi_3O_7$ up to about 18 weight per cent of $CaSi_3O_7$ and these mix-crystals have $N_o = 1.629$, $N_e = 1.630$, $N_e - N_o = 0.001$. Similarly, $(Ca_2MgSi_2O_7 + Ca_2Al_2SiO_7)$ is miscible with 14 per cent of $CaSi_3O_7$ and 10 per cent of $Na_2Si_3O_7$ and these mix-crystals have $N_o = 1.632$, $N_e = 1.627$, $N_o - N_e = 0.005$.

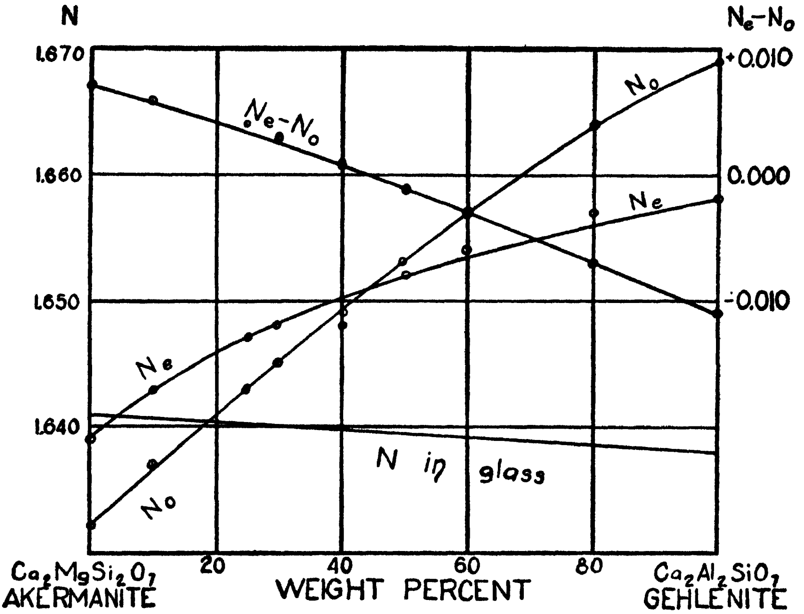

FIG. 259.—Variations in composition and optic properties in the $Ca_2MgSi_2O_7$-$Ca_2Al_2SiO_7$ series. (After Ferguson and Buddington: *Am. Jour. Sci.* L, 1920, p. 131.)

$Ca_2MgSi_2O_7$ is miscible in all proportions with $Ca_2Al_2SiO_7$, forming thus the ***akermanite-gehlenite*** series in which the optic properties vary with the variations in composition as shown[13] in Fig. 259.

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[10] A. N. Winchell: *Am. Jour. Sci.*, CCVIII, 1924, p. 375.

[11] A. F. Buddington: *Am. Jour. Sci.*, CCIII, 1922, p. 35.

[12] *Am. Mineral.*, XIV, 1929, p. 389.

[13] J. B. Ferguson and A. F. Buddington: *Am. Jour. Sci.*, CC, 1920, p. 131.

$CaCuSi_4O_{10}$ is tetragonal with G. = 3.04 (Fouqué)[14] 2.95 (Laurie);[15] uniaxial negative with $N_o = 1.6354$, $N_e = 1.6053$, $N_o - N_e = 0.0301$, Color azure blue with X = pale rose, Z = deep blue. Made from fusion and called *Vestorian blue*; supposed to be the equivalent of an artificial blue pigment used by the early Egyptians.

$FeBaSi_4O_{10}$ is tetragonal[16] with perfect 001 and poor 100 cleavages. H. = 3. G. = 3.33. F. = easy. Attacked by HCl. Uniaxial negative with $N_o = 1.621$, $N_e = 1.619$, $N_o - N_e = 0.002$. Color rose red with X = red, Z = pale pink to colorless with striking pleochroism in thin section. The natural substance is called *gillespite*. Treatment with HCl removes all the iron and barium leaving hydrous silica ($8SiO_2 \cdot 5H_2O$), which dehydrates gradually between 0° C. and ignition, having about 2.5 per cent H_2O still at 400° C. This hydrous silica is in glistening scales resembling those produced by treating biotite with H_2SO_4. They are uniaxial negative or slightly biaxial with variable indices: $N_o = 1.465$ and 1.449, $N_e = 1.455$ and 1.441, $N_o - N_e = 0.010$ and 0.008. Colorless.

Be_2SiO_4 is trigonal with $c = 0.661$. Crystals rhombohedral or prismatic with twinning common on $10\bar{1}0$ and distinct $11\bar{2}0$ cleavages. H. = 7.5. G. = 3.0. F. = 7. Insoluble in acid. Uniaxial positive[17] with $N_o = 1.654$, $N_e = 1.668$, $N_e - N_o = 0.016$. Colorless. The natural substance, called *phenacite*, is found in pegmatite and some metamorphic rocks; rare.

$SrSiO_3$ is hexagonal[18] with $c = 1.015$ in thick basal plates with good 0001 cleavage and twinning on 0001. G. = 3.65. F. = 1580° C. Uniaxial positive with $N_o = 1.596$ C, 1.599 D, 1.606 F, $N_e = 1.634$ C, 1.637 D, 1.646 F, $N_e - N_o = 0.038$ D. Miscible in all proportions with $CaSiO_3$; if 1 : 1, (+) $2V = 0°\pm$, $N_g = 1.646$ D, $N_m = N_p = 1.606$, $N_g - N_p = 0.040$, as shown in Fig. 260. No inversion found. Colorless. Made from fusion. The glass has G. = 3.54, N = 1.632.

$Ca_2BaSi_3O_9$ is hexagonal[18] (?); fibrous with good prismatic cleavages; it dissociates to $CaSiO_3$ and liquid at 1320° C. The fibers have negative elongation; they are uniaxial negative with $N_o = 1.677$ C, 1.681 D, 1.690 F, $N_e = 1.664$ C, 1.668 D, 1.678 F, $N_o - N_e = 0.013$ D. Colorless. Made from fusion.

Ba_2SiO_4 is granular[18] without cleavage or twinning; melting point about that of Pt. $N_g = 1.83$, $N_p = 1.81$, N_g $N_p = 0.02$ Na. Colorless. Made from fusion.

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[14] *Comp. Rend.*, CVIII, 1889, p. 325.

[15] *Proc. Roy. Soc.*, LXXXIX, A, 1914, p. 418.

[16] W. T. Schaller: *Am. Mineral.*, XIV, 1929, p. 319.

[17] H. Michel: *Zeit. Kryst.*, LIII, 1914, p. 538.

[18] P. Eskola: *Am. Jour. Sci.*, CCIV, 1922, p. 331.

Ca_3SiO_5 is granular[19] without cleavage; also fibrous;[20] dissociates to CaO and Ca_2SiO_4 at about 1900° C. Lamellar twinning with a small extinction angle. Uniaxial negative, or (−) 2V = small. $N_m = 1.715$, $N_g - N_p$ = weak, not over 0.005. Colorless. Made from glass at about 1800° C.

$Ca_3Si_2O_7$ is orthorhombic[21] (?) and granular; dissociates to Ca_2SiO_4 at about 1475° C. (+) 2V = large, $N_g = 1.650$, $N_m = 1.645 \pm$, $N_p = 1.641$, $N_g - N_p = 0.009$ Na. Colorless. Made from fusion at about 1450° C.

$Ca_5Mg_2Si_6O_{19}$ is orthorhombic[21] (?) in elongated grains; dissociates at about 1365° C. Forms mix-crystals with $CaSiO_3$, etc. Elongation parallel to Y. (+) 2V = 80° ±, $N_g = 1.635$, $N_m = 1.627$, $N_p = 1.621$, $N_g - N_p = 0.014$. Colorless. Made from fusion at about 1350° C.

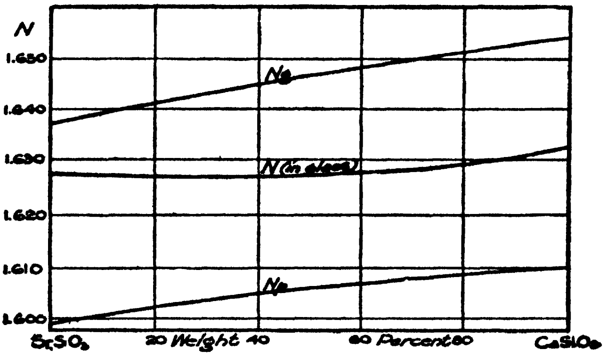

FIG. 260.—Variations in composition and optic properties in the $SrSiO_3$–$CaSiO_3$ series. Positive and nearly uniaxial; therefore N_m nearly = N_p. Based on data of P. Eskola: *Am. Jour. Sci.* IV, 1922, p. 331.

$BaSi_2O_5$ is orthorhombic[18] with three pinacoidal cleavages, one (assumed to be 010) perfect; others distinct. Crystals elongated in direction assumed to be *c*. G. = 3.73. F. = 1420° C. The optic plane then is 100; X = *c*. (−) 2V = 75°, N_g = 1.618 C, 1.621 D, 1.632 F, N_m = 1.610 C, 1.612 D, 1.617 F, N_p = 1.595 C, 1.597 D, 1.602 F, $N_g - N_p$ = 0.024 D. In optical glass $BaSi_2O_5$ has $N_g = 1.613$, $N_p = 1.595$

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[19] G. A. Rankin: *Jour. Am. Chem. Soc.*, XXXVIII, 1916, p. 568.

[20] *Jour. Phys. Chem.*, XXXI, 1927, p. 607.

[21] J. B. Ferguson and H. E. Merwin: *Am. Jour. Sci.*, CXCVIII, 1919, p. 81.

(due to $K_2Si_2O_5$ in crystal solution?). $BaSi_2O_5$ forms a continuous series of mix-crystals with $Ba_2Si_3O_8$, in which the optic properties vary as shown in Fig. 261, according to the author's interpretation of Eskola's data. $BaSi_2O_5$ glass has N = 1.606. Colorless. Made from fusion.

$Ba_2Si_3O_8$ is orthorhombic [18] and granular with three pinacoidal cleavages, one (assumed to be 001) perfect; others poor. Lamellar twinning on a prism face inclined 30° to *a*. G. = 3.93. F. = 1450° C. The optic plane is then 100; X = *c*. (+) 2V = 54°, N_g = 1.641 C, 1.645 D, 1.652 F, N_m = 1.622 C, 1.625 D, 1.632 F, N_p = 1.617 C, 1.620 D, 1.627 F, $N_g - N_p$ = 0.025 D. $Ba_2Si_3O_8$ forms a complete series of crystal solutions with $BaSi_2O_5$, the optical properties varying continuously, as shown in Fig. 261. Colorless. Made from fusion.

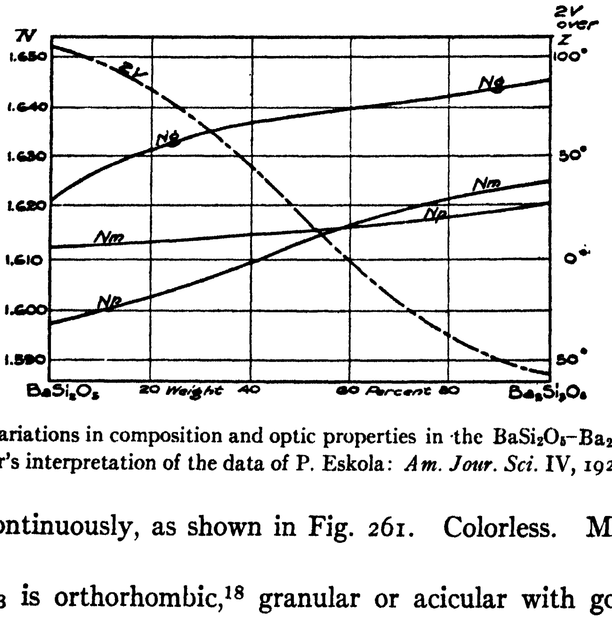

FIG. 261.—Variations in composition and optic properties in the $BaSi_2O_5$–$Ba_2Si_3O_8$ series. The author's interpretation of the data of P. Eskola: *Am. Jour. Sci.* IV, 1922, p. 331.

$BaSiO_3$ is orthorhombic,[18] granular or acicular with good pinacoidal cleavage assumed to be 010. G. = 4.4. F. = 1604° C. Elongation (assumed parallel to *c*) is negative. The optic plane is then 100; X = *c*. (+) 2V = 29°, $\rho > v$ strong, N_g = 1.673 C, 1.678 D, 1.688 F, N_m = 1.670 C, 1.674 D, 1.684 F, N_p = 1.669 C, 1.673 D, 1.682 F, $N_g - N_p$ = 0.005 D. Colorless. Made from fusion.

$ZnSiO_3$ is weakly birefringent,[22] but of unknown symmetry. Crystalline masses are aggregates of thin needles resembling porcelain. G. = 3.52, F. = 1429° C. N_1 = 1.623, N_2 = 1.616. Colorless. Made from fusion. The glass has G. = 3.86 and N = 1.650.

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[22] F. M. Jaeger: *Proc. K. Akad. Wet. Amst.*, XVIII, 1916, p. 896. Symmetry reported as orthorhombic by Traube and hexagonal by van Klooster.

Ca_2SiO_4 has at least three crystal phases.[21] The α-phase, stable from 1420° C. to fusion at 2130° C., is probably monoclinic; it has lamellar twinning, which may be complex, and the maximum extinction angle in flakes with one twinning is $X' \wedge c = 18°$. H. = 5–6. The optic plane is nearly parallel with the vertical elongation. (+) 2V = large. $N_g = 1.737$, $N_m = 1.720$, $N_p = 1.715$, $N_g - N_p = 0.023$ Na. Colorless. Made from fusion or from glass above 1420° C. and quenching. A natural mineral, called *larnite*[23] is probably the same as this phase. It has distinct cleavage and twinning on 100. The optic plane and Z are normal to 010; $X \wedge c = 14°$. (+) 2V = large. $N_g = 1.730$, $N_m = 1.715$, $N_p = 1.707$, $N_g - N_p = 0.023$. Colorless.

The β-phase is orthorhombic prismatic or granular with distinct 010 and 100 cleavages. Lamellar. Twinning rare. Stable from 675° to 1420° C. H. = 5–6. Strongly attacked by water with solution of lime. Soluble in HCl. The optic plane is 100; X = *c*. (+) 2V = large, $N_g = 1.735$, $N_m = ?$, $N_p = 1.717$, $N_g - N_p = 0.018$. Colorless. Made by quenching from about 1000° C. or slower cooling if enclosed in glass or other minerals. The natural substance has been called lime-olivine or *shannonite*;[24] it is very rare.

The γ-phase is probably monoclinic; prismatic with perfect 010 cleavage. Stable below 675° C. $Z \wedge c = 3°$. (+) 2V = 60°, $N_g = 1.654$, $N_m = 1.645$, $N_p = 1.642$, $N_g - N_p = 0.013$. Colorless. In its refringence this phase corresponds with the olivine minerals. The reversible inversion from the β-phase to the γ-phase at 675° C. is accompanied by a ten per cent increase of volume which shatters the material, causing the " dusting " of Portland cement.

Still another phase (called β′) was apparently obtained by quenching an old hydrated preparation from about 1425° C.; it had no apparent cleavage; (+) 2V = 0° or very small, $N_m = 1.715$, $N_g - N_p$ = very weak; this phase is supposed to be unstable and monotropic.

Mg_2SiO_4 is orthorhombic[25] with $a : b : c = 0.467 : 1 : 0.587$; crystals short prismatic with distinct 001 and 010 cleavages. G. = 3.216. F. = 1890° C. Gelatinizes with HCl. The optic plane is 001; Z = *a*. (+) 2V = 84° 55′ C, 85° 16′ D, 85° 40′ F, $N_g = 1.6655$ C, 1.6688 D, 1.6764 F, $N_m = 1.6475$ C, 1.6507 D, 1.6582 F, $N_p = 1.6329$ C, 1.6359 D, 1.6431 F, $N_g - N_p = 0.0329$. Colorless. Made from fusion in $MgCl_2$. The natural substance, called *forsterite*, is an end member of the olivine system.

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[23] C. E. Tilley: *Mineral. Mag.*, XXII, 1929, p. 77.

[24] A. N. Winchell: *Optical Mineralogy*, Part II, 1927, p. 164.

[25] N. L. Bowen and O. Andersen: *Am. Jour. Sci.*, CLXXXVII, 1914, p. 487. H. E. Merwin: *Int. Crit. Tab.*, VII, 1930, p. 23.

Mg_2SiO_4 may form a submicroscopic intergrowth [26] with SiO_2 glass in varying amounts up to about 50 mol. per cent (thus corresponding in gross composition with $MgSiO_3$); with that amount of SiO_2 glass, the aggregate has the following properties: (+) 2V = large, $N_g = 1.597$, $N_m = 1.590$ (est.), $N_p = 1.584$, $N_g - N_p = 0.013$. Extinction parallel. Colorless to pale brown with Y = light brown, Z = brown. In optical properties it is therefore similar to the orthorhombic amphibole called *anthophyllite*, but the latter contains water and has the composition: $H_2Mg_7Si_8O_{24}$.

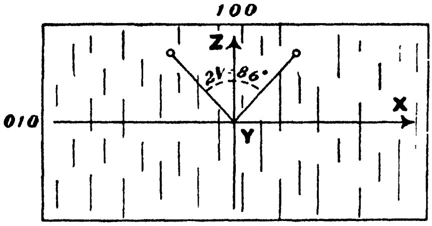

FIG. 262.—Optic orientation of Mg_2SiO_4.

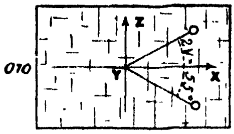

FIG. 263.—Optic orientation of Fe_2SiO_4

Fe_2SiO_4 is orthorhombic [27] in 100 tablets, etc., with distinct 010 and poor 100 cleavages. G. = 4.32. Gelatinizes with HCl. The optic plane is 001; X = *b*. (−) 2V = 47°, $N_g = 1.886$, $N_m = 1.877$, $N_p = 1.835$, $N_g - N_p = 0.051$. Colorless to greenish yellow. Made in slag. The natural substance, called *fayalite*, is an end member of the olivine system.

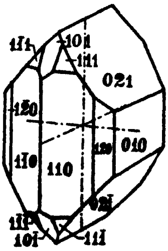

FIG. 264.—A crystal habit of $(Mg,Fe)_2SiO_4$ (olivine).

Mn_2SiO_4 is orthorhombic [22] in crystals like olivine, with distinct 010 cleavage. H. = 6. G. = 4.04. F. = 1290°–1320° C. Gelatinizes with HCl. The optic plane is 001; X = *b*. (−) 2V = 65°, $N_g = 1.80\pm$, $N_m = 1.78\pm$, $N_p = 1.76\pm$, $N_g - N_p = 0.04\pm$ (nat. cryst.); $N > 1.74$ (art. cryst.). Color ash gray to rose red. In thin section nearly colorless; in thick sections X = brownish red, Y = reddish, Z = greenish blue and $X < Z < Y$. Made from fusion. The natural substance, called *tephroite*, found in ore deposits, is a third end member of the olivine system. According to Tokody[28] Mn_2SiO_4 forms mix-crystals with Ca_2SiO_4 up to 50 mol. per cent (which is called *glaucochroite*, as found in nature) and perhaps beyond.

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[26] N. L. Bowen: personal communication, Jan. 9, 1931.

[27] K. Busz and F. W. Rüsberg: *Cent. Min.*, 1913, p. 625.

Mg_2SiO_4 and **Fe_2SiO_4** intercrystallize in various proportions in natural crystals to form the *olivine* series. In nature the commonest type, called *chrysolite*, is rich in Mg (Mg : Fe = 4 to 8 : 1 commonly); in slags the common types are those rich in Fe (often with Mn or Zn or both). In the olivine series the varieties may be defined as follows:

	Mg_2SiO_4	Fe_2SiO_4	
Forsterite	100–95%	0–5%	
Chrysolite	95–75	5–25	
Hyalosiderite	75–50	25–50	
Hortonolite	50– ?	?–50	(Usually with Zn)
Fayalite	5–0	95–100	

Varieties between hortonolite and fayalite seem to be rare.

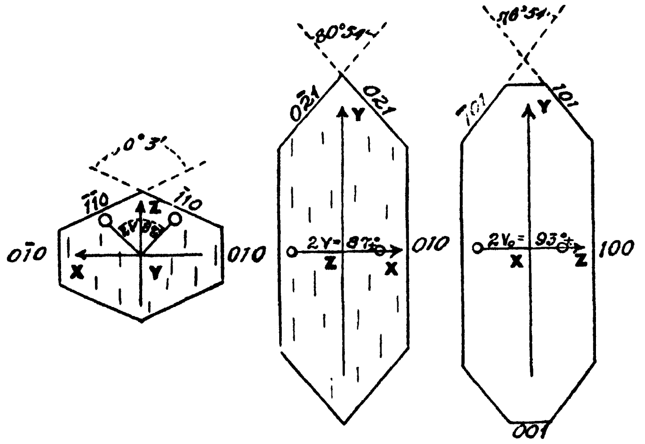

FIG. 265. FIG. 266. FIG. 267.

FIGS. 265–267.—Optic orientation of $(Mg,Fe)_2SiO_4$ (olivine).

The plane of the optic axes is 001 and X is normal to 010 in all members of the olivine series. The optic angle is large (except in fayalite – 2V = 47°) and varies through 90° with change of sign at about 13 per cent Fe_2SiO_4. The relations between optic properties and composition are shown in Fig. 268. For the highly magnesian types: (+) $2V = 70° - 90°$, $N_g = 1.67—1.69$, $N_m = 1.65—1.67$, $N_p = 1.635 — 1.655$, $N_g - N_p = 0.035\pm$. For more ferriferous types:

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[28] *Zeit. anorg. Chem.*, CLXIX, 1928, p. 51.

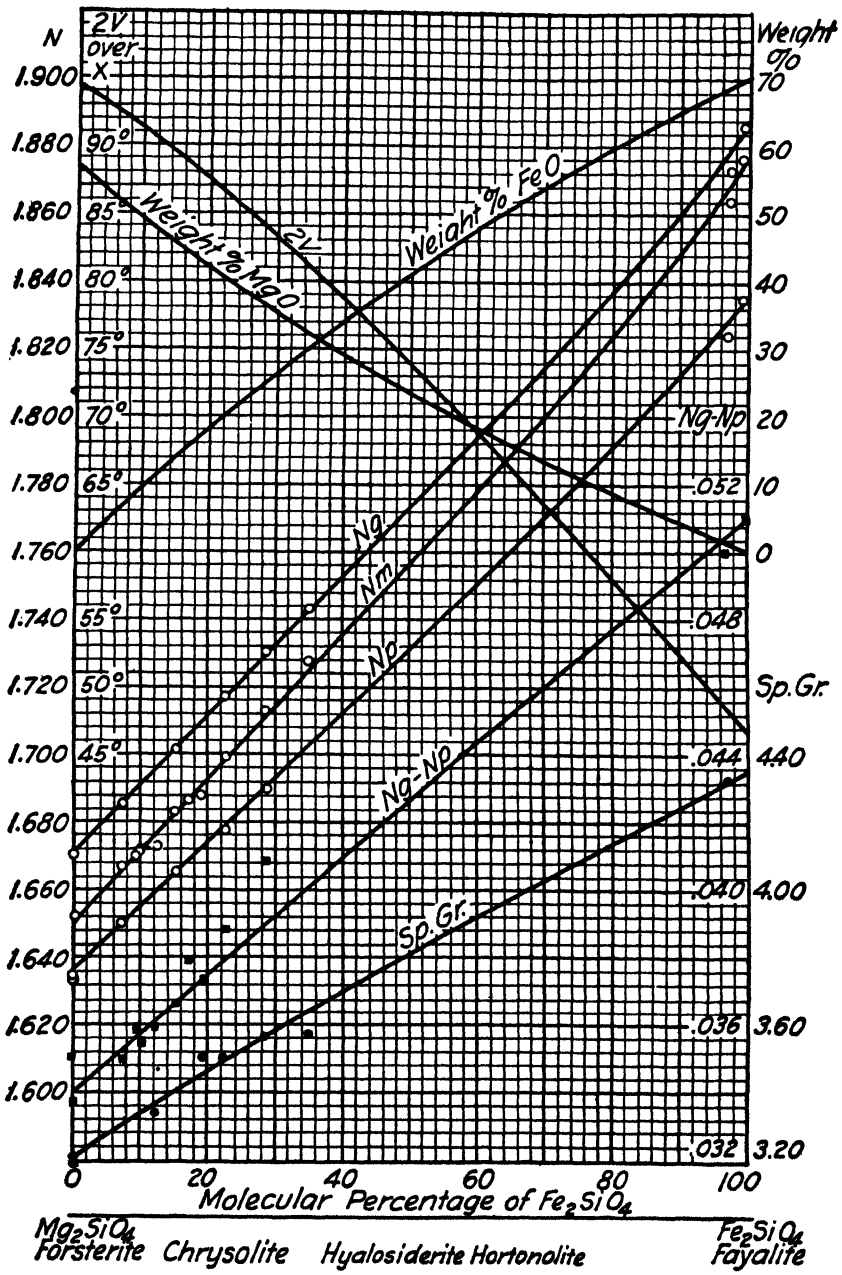

FIG. 268.—Variations in composition and optic properties in the Mg_2SiO_4–Fe_2SiO_4 series.

(–) $2V = 90°–75°$, $N_g = 1.69–1.77$, $N_m = 1.67–1.75$, $N_p = 1.655–1.72$, $N_g - N_p = 0.035–0.040$. For highly ferriferous types: (–) $2V = 75°–45°$, $N_g = 1.77–1.88$, $N_m = 1.75–1.87$, $N_p = 1.72–1.83$, $N_g - N_p = 0.040–0.050$. Color olive green; alters easily to yellow, brown or red. Colorless to very pale greenish in thin section without pleochroism.

Fe_2SiO_4 and **Mn_2SiO_4** intercrystallize probably in all proportions to form a series (of the *olivine* system) which has not been studied in detail. From scanty data the relations between optic properties and composition in the ternary system Mg_2SiO_4–Fe_2SiO_4–Mn_2SiO_4 seem to be about as shown in Fig. 269.

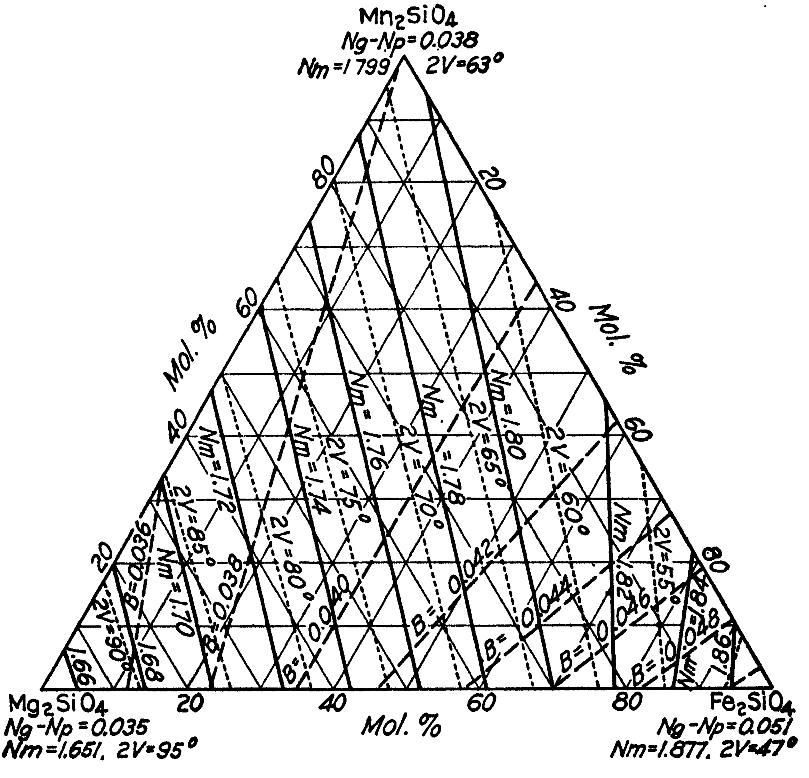

FIG. 269.—Variations in composition and optic properties in the Mg_2SiO_4–Fe_2SiO_4–Mn_2SiO_4 system.

$CaMgSiO_4$ is orthorhombic granular with poor 010 cleavage. G. = 3.2. Gelatinizes with HCl. The optic plane is 001; X = *b*. Optic properties of the pure substance unknown; with 10 per cent Mg_2SiO_4 it has[21] (+) $2V = 85°–90°$, $N_g = 1.651–1.655$, $N_m =$

1.646, N_p = 1.638–1.640, $N_g - N_p$ = 0.015±. With 16 per cent $(Mg, Fe)_2SiO_4$ it has[29] (−) 2V = 74½°, N_g = 1.680, N_m = 1.674, N_p = 1.663, $N_g - N_p$ = 0.018. Colorless. Dissociates before melting. Made from fusion at about 1490° C. The natural substance, called *monticellite,* is found occasionally near contacts of dolomite with igneous intrusions.

$CaFeSiO_4$ is orthorhombic[30] with $a : b : c = 0.437 : 1 : 0.577$. G. = 3.33. Gelatinizes with HCl. The optic plane is 001; X = *b*. (−) 2V = 48° 40′, $\rho > v$ moderate. N_g = 1.743, N_m = 1.734, N_p = 1.696, $N_g - N_p$ = 0.047. Also reported with N_p > 1.74. Color pale yellow. Made in a steel bomb. A related type[27] with 35.11 CaO, 18.97 FeO and 11.21 MnO has: G. = 3.34, N_g = 1.7105, N_m = 1.7004 (636), 1.7054 (578), 1.7133 (513), 1.7162 (470), N_p = 1.6749, $N_g - N_p$ = 0.0356.

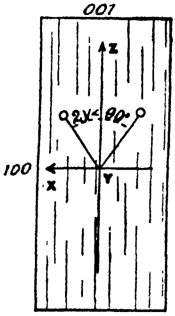

FIG. 270.—Optic orientation of $MgSiO_3$ (enstatite).

$MgSiO_3$ has two crystal phases.[31] The α-phase, apparently the most stable at all temperatures, is monoclinic with $a : b : c = 1.033 : 1 : 0.591$, $\beta = 87°$ 36′. Crystals prismatic or 100 tablets with perfect 110 cleavage at 88° 8′ and 001 parting. Lamellar twinning on 100 is very characteristic, but may be rare.[32] H. = 6. G. = 3.19. Miscible in all proportions with $CaMgSi_2O_6$ *at high temperature,* the optic properties varying as shown in Fig. 272. Begins to dissociate to Mg_2SiO_4 and liquid at 1557° C. and fusion is complete at 1577° C. Insoluble in HCl. The optic plane is normal to 010; $Z \wedge c = +22°$. (+) 2V = 53½°, N_g = 1.660, N_m = 1.654 (calc.), N_p = 1.651, $N_g - N_p$ = 0.009. Colorless. Made from fusion at about 1550° C. The natural substance, called *clinoenstatite,* is a *pyroxene* quite rare in rocks and meteorites.

$MgSiO_3$ glass has[33] G. = 2.758 and N = 1.5767 Li, 1.5801 Na, 1.5833 Tl.

The β-phase is orthorhombic; crystals prismatic to fibrous parallel to *a* with 110 cleavage at nearly 90°. Twinning rare. H. = 6. G. = 3.175. Changes to the α-phase quickly at about 1500° C., and the change is not reversible. The optic plane is 010; Z = *c*. (+) 2V = 31°, $N_g = 1.658$, $N_m = 1.653$, $N_p = 1.650$, $N_g - N_p = 0.008$. Colorless. Crystallizes from the glass at about 1050° C. The natural substance, called *enstatite*, is a *pyroxene* not rare in igneous rocks, but nearly always containing some iron, the effects of which on the optic properties are shown in Fig. 271.

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[29] A. F. Hallimond: *Mineral. Mag.,* XIX, 1921, p. 193.

[30] K. H. Degen: *Tables Ann. Int. Const.,* V, 1926; also P. Niggli: *Zeit. anorg. Chem.,* LXXXVII, 1914, p. 66.

[31] Allen, Wright, and Clement: *Am. Jour. Sci.,* CLXXII, 1906, p. 385; Allen, White, Wright and Larsen: *Am. Jour. Sci.,* CLXXVII, 1909, p. 1; Bowen and Andersen: *Am. Jour. Sci.,* CLXXXVII, 1914, p. 487; N. L. Bowen: *Am. Jour. Sci.,* CLXXXVIII, 1914, p. 207. Ferguson and Merwin: *Am. Jour. Sci.,* CXCVIII, 1919, p. 81.

[32] G. A. Rankin and H. E. Merwin: *Am. Jour. Sci.,* CXCV, 1918, p. 301.

[33] E. S. Larsen: *Am. Jour. Sci.,* XXXVIII, 1909, p. 263.

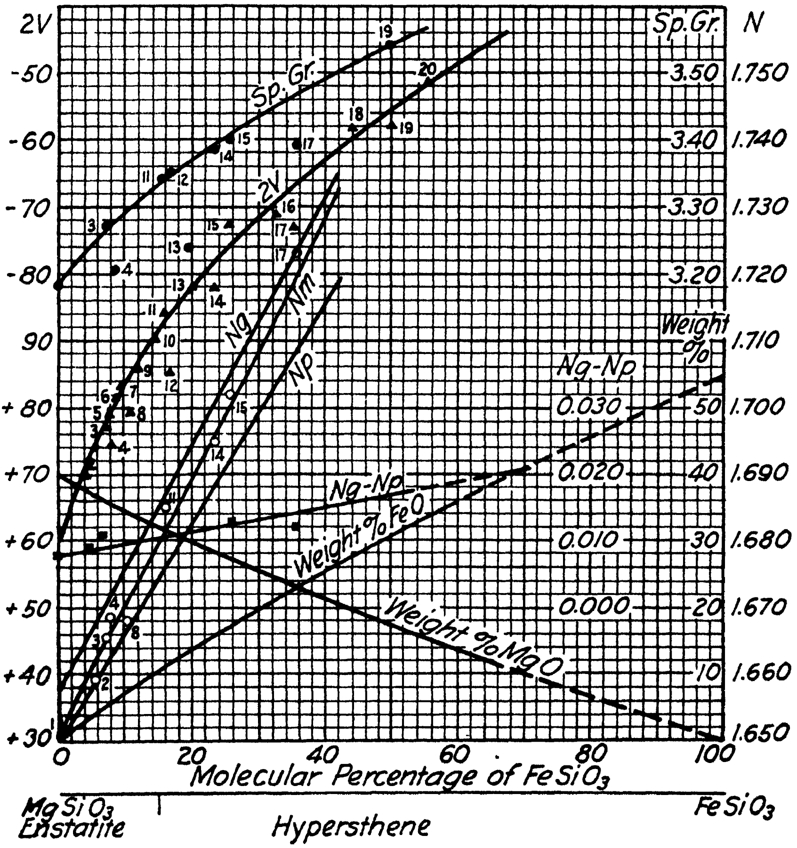

FIG. 271.—Variations in composition and in optic properties in the $MgSiO_3$–$FeSiO_3$ orthorhombic series.

$CaMgSi_2O_6$ is monoclinic[34] with *a* : *b* : *c* = 1.096 : 1 : 0.591, β = 73° 59′. Crystals short prismatic as in Fig. 273, with perfect 110 cleavages at about 87° and also a domatic parting at about 66° to *c*. Simple twinning on 100. H. = 5–6. G. = 3.275. F. = 1391° C. Insoluble in HCl. Miscible in all proportions with $CaFeSi_2O_6$, and also, *at high temperature*, with α-$MgSiO_3$ (see Fig. 272). The optic plane is 010; $Z \wedge c = +38.5°$. (+) $2V = 59°$, $\rho > v$ weak. $N_g = 1.6945$, $N_m = 1.6681$ C, 1.6713 D, 1.6790 F, $N_p = 1.6646$, $N_g - N_p = 0.030$. Colorless. Made from fusion. The natural substance, called *diopside*, is an important member of the *pyroxene* group, but is almost never free from iron, etc.

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[34] Allen, White, Wright and Larsen: *Am. Jour. Sci.*, CLXXVII, 1909, p. 1.

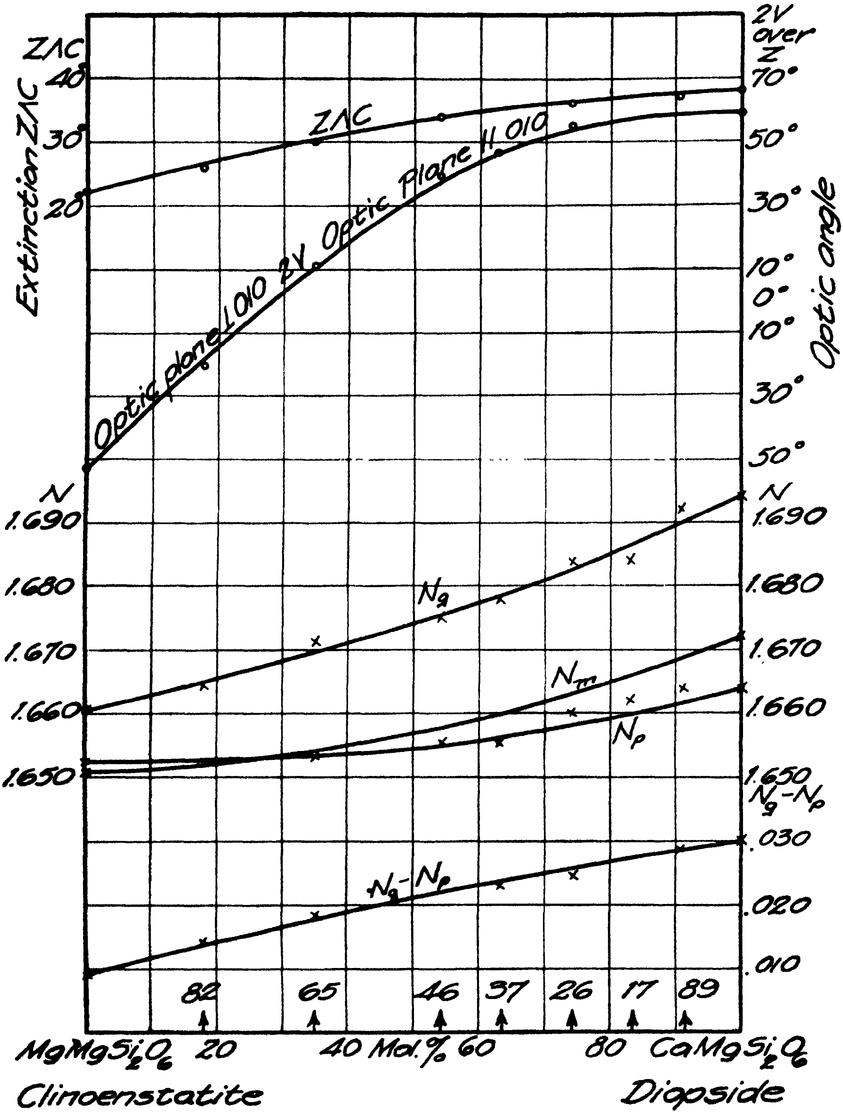

FIG. 272.—Variations in composition and optic properties in the $Mg_2Si_2O_6$–$CaMgSi_2O_6$ series.

$CaFeSi_2O_6$ is monoclinic; it was probably produced by Schlæpfer and Niggli[35] by the hydrothermal method. Perfect 110 cleavage. Insoluble in HCl. The optic plane is 010; $Z \wedge c = 46°–47°$. $N_g > 1.76 > N_p$, $N_g - N_p = 0.03$. Color pale yellowish green. The natural substance, called *hedenbergite*, is an important member of the *pyroxene* group, but is not found pure in nature.

$CaMgSi_2O_6$ and **$CaFeSi_2O_6$** are miscible in all proportions as crystals and the series is an important part of the *pyroxene* group. Crystals are short prismatic with perfect 110 cleavages at about 87°; simple twinning on 100 not rare. H. = 5–6. G. = 3.275–3.55. Insoluble in HCl. The optic plane is 010; $Z \wedge c = 38°–47°$. (+) $2V = 59°–60°$. $N_g = 1.69–1.76$, $N_m = 1.67–1.75$, $N_p = 1.66–1.74$, $N_g - N_p = 0.030–0.018$. The relations between optic properties and composition are shown in Fig. 276 which is based largely on natural minerals.

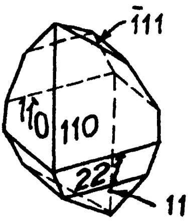

FIG. 273.—A crystal habit of $CaMgSi_2O_6$ (diopside).

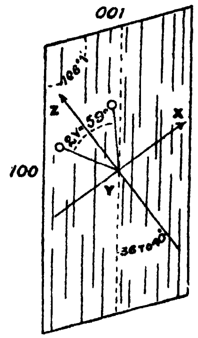

FIG.—274. Optic orientation of $CaMgSi_2O_6$ (diopside).

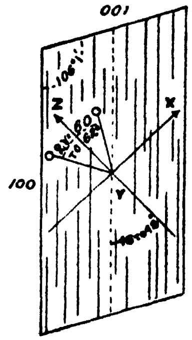

FIG. 275.—Optic orientation of $CaFeSi_2O_6$. (Hedenbergite).

Sr_2SiO_4 is probably monoclinic,[18] commonly twinned on 100. F. = 7. The optic plane is normal to 010; $X \wedge c = 17°$. (+) $2V = 32\frac{1}{2}°$, $N_g = 1.752$ C, 1.756 D, 1.766 F, $N_m = 1.727$ C, 1.732 D, 1.744 F, $N_p = 1.722$ C, 1.7275 D, 1.740 F, $N_g - N_p = 0.0285$ D. No inversion found. Colorless. Made by heating at high temperature.

$CaSiO_3$ has two crystal phases.[36] The α-phase is pseudohexagonal and probably monoclinic in equant grains with 001 cleavage and H. = 5. G. = 2.905. F. = 1540° C. It can take into crystal solution up to 2 per cent SiO_2, 16 per cent $CaMgSi_2O_6$, 25 per cent $Ca_2MgSi_2O_7$, 20 per cent $Ca_3Si_2O_7$, or 100 per cent $SrSiO_3$. Solid solution of about

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[35] *Zeit. anorg. Chem.*, LXXXVII, 1914, p. 52.

[36] Ferguson and Merwin: *Am. Jour. Sci.*, CLXXI, 1906, p. 89; CXCVIII, 1919, p. 81, 165. Rankin and Wright: *Am. Jour. Sci.*, CLXXXIX, 1915, p. 1. P. Eskola: *Am. Jour. Sci.*, IV, 1922, p. 331.

3 per cent MgO lowers N_g about 0.006 with no other effect on the optic properties. (+) 2E = 0°–8°, N_g = 1.649 C, 1.654 D, 1.663 F, $N_m = N_p$ = 1.607 C, 1.610 D, 1.618 F, $N_g - N_p$ = 0.044. It may show

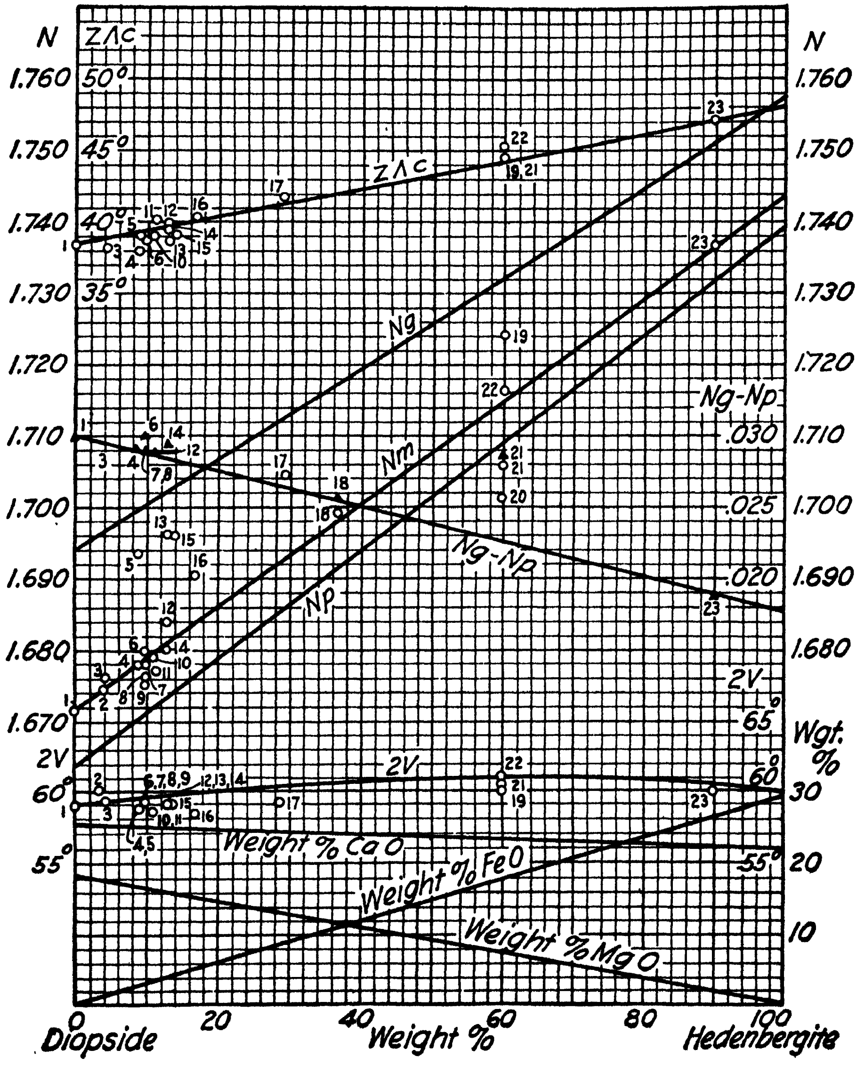

FIG. 276.—Variations in composition and optic properties in the $CaMgSi_2O_6$–$CaFeSi_2O_6$ or diopside-hedenbergite series.

lamellar twinning on 001 with X ∧ *a* = 3°. Colorless. Stable above 1200° C. Made from fusion and found in some slags; called *pseudo-wollastonite.*

The β-phase is monoclinic;[36] crystals lath-shaped with perfect 100 and good 001 cleavages. H. = 5. G. = 2.915. Inverts at 1200° to the α-phase. Decomposed by HCl. The optic plane is normal to cleavage lines and elongation (b), with parallel extinction. (−) $2V = 39°$, $N_g = 1.631$, $N_m = 1.629$, $N_p = 1.616$, $N_g - N_p = 0.015$. Colorless. Made by crystallization of the glass at about 1000° C. It can take into crystal solution up to 3 per cent SiO_2, 17 per cent $CaMgSi_2O_6$, 65 per cent $Ca_2MgSi_2O_7$ or 45 per cent $Ca_3Si_2O_7$. The natural substance, called *wollastonite*, is found at limestone contacts. $CaSiO_3$ glass has[33] G. = 2.904 and N = 1.6241 Li, 1.6280 Na, 1.6317 Tl.

$Ca(Fe,Mn,Mg)_2Si_3O_9$ is triclinic[37] with $a : b : c = 1.093 : 1 : 0.729$, $\alpha = 99° 37'$, $\beta = 99° 21'$, $\gamma = 83° 53'$. Crystals 110 plates with perfect 110 and $1\bar{1}0$ cleavages. G. = 3.39. The optic axes are nearly normal to the cleavages; extinction normal to X is at 5° and normal to Z is nearly 0°. (−) $2V = 65\frac{1}{2}°$, $N_m = 1.701$, $N_g - N_p = 0.018$. Color pale yellow, not pleochroic. Forms in acid steel-furnace slags, and has been named *vogtite*.

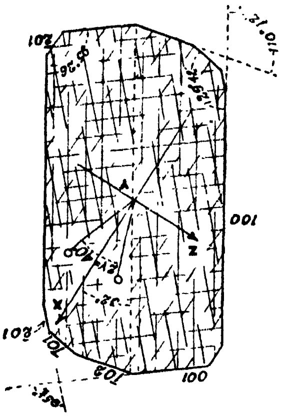

FIG. 277.—Optic orientation of $CaSiO_3$ (wollastonite).

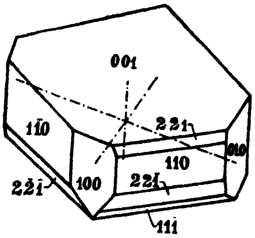

FIG. 278.—A crystal habit of rhodonite.

$MnSiO_3$ is triclinic;[38] crystals prismatic with 110, $1\bar{1}0$, and 001 cleavages. See Fig. 278. H. = 5. G. = 3.63 (Kallenberg) or 3.716 (Jaeger). F. = 1273° C. Extinction on 100 at 31° to c. Biaxial and positive (Kallenberg). $N_1 = 1.739$, $N_2 = 1.733$, $N_g - N_p = 0.007$ (Jaeger); N = 1.714 (Kallenberg). The glass has G. = 3.48, N = 1.700 (Jaeger). Color pink. Made by fusion. The natural substance, called *pyroxmangite*, is similar but contains Fe. *Rhodonite* seems to be different,[39] containing Ca, but the evidence is not conclusive. According to Hey[40] there is a continuous series from $MnSiO_3$ to at least 50 per cent $CaSiO_3$, available data on this (continuous?) series are assembled in Fig. 279.

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[37] A. F. Hallimond: *Min. Mag.*, XVIII, 1919, p. 368.

[38] S. Kallenberg: *Cent. Min.*, 1914, p. 388. F. M. Jaeger: *Proc. K. Akad. Wet. Amsterdam*, LVIII, 2, 1916, p. 896.

$Ca_2Pb(SiO_3)_3$ is biaxial with[41] G. = 3.99 and N_m = 1.795.

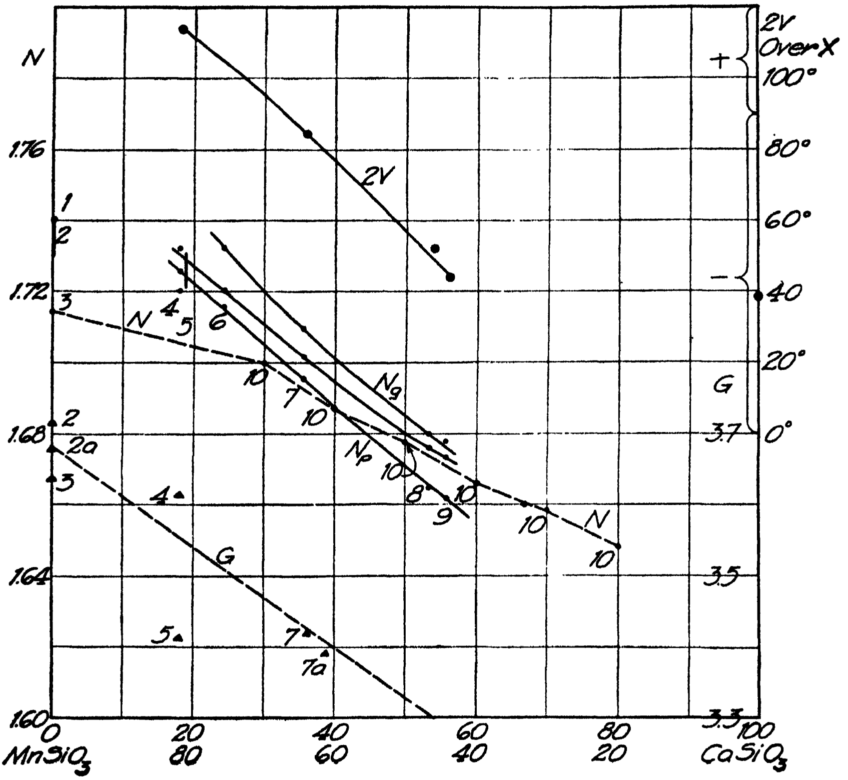

FIG. 279.—Variations in composition and optic properties in the $MnSiO_3$–$CaSiO_3$ series.

5. HYDROUS SILICATES OF DIVALENT BASES

$Ca_2SiO_4 \cdot H_2O$ (?) is orthorhombic[35] in acicular groups. Soluble in HCl. Positive elongation and parallel extinction. $N_g = 1.612$, $N_m = 1.61\pm$, $N_p = 1.605$, $N_g - N_p = 0.007$. Colorless. Apparently the same as the natural *hillebrandite*.

$BaSiO_3 \cdot 6H_2O$ is orthorhombic[42] with $a : b : c = 0.856 : 1 : 0.563$.

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[39] A. N. Winchell: *Am. Mineral.*, XII, 1927, p. 10.

[40] M. H. Hey: *Mineral Mag.*, XXII, 1929, p. 193.

[41] *Int. Crit. Tables*, I, 1926, p. 144.

[42] Wahl: *Zeit. Kryst.*, XXXVI, 1902, p. 156.

Crystals prismatic often with 210, 100, 010, 111, 021. G. = 2.58–2.60. Optic plane is 010; X = *a*. (−) 2V = 39° 40′ Na, $\rho > v$ very strong. $N_g = 1.548$, $N_m = 1.547$ (calc.), $N_p = 1.542$, $N_g - N_p = 0.006$. Colorless.

$\mathbf{H_2Ca_2Mg_5Si_8O_{24}}$ is monoclinic with $a : b : c = 0.541 : 1 : 0.288$, $\beta = 74° \ 48'$, H. = 5–6. G. = 2.9. Perfect 110 cleavage at 124°. Insoluble in acids. The optic plane is 010; $Z \wedge c = 18° \pm$. (−) 2V = 88°, $N_g = 1.625$, $N_m = 1.613$, $N_p = 1.599$, $N_g - N_p = 0.026$ (nat. cryst.). Colorless. The natural substance, called *tremolite*, is not rare. There is a gradation from the nearly pure substance to the ferrous iron equivalent, $\mathbf{H_2Ca_2Fe_5Si_8O_{24}}$, known as *actinolite*, which is very similar in shape and cleavages. In it the optic plane is 010; $Z \wedge c = 10° \pm$; (−) 2V = 75°; $N_g = 1.685$, $N_m = 1.67\pm$, $N_p = 1.668$, $N_g - N_p = 0.017$ (nat. cryst.). Color green with X = pale yellow, Y = greenish yellow, Z = green. When these minerals are heated to about 800° C. the hydrogen may be driven off with very little effect upon the optic properties of tremolite,[43] but increasingly important effects upon members of the series containing increasing amounts of iron. Barnes[43] has shown that this is due to oxidation of the iron. After heating a member of the series with about 20 per cent of the iron molecule the extinction angle ($Z \wedge c$) had changed from 15° to 10°, the optic angle from 73° to 56° and the indices from $N_g = 1.6413$, $N_m = 1.6313$, $N_p = 1.6133$, $N_g - N_p = 0.0280$ to $N_g = 1.6728$, $N_m = 1.6634$, $N_p = 1.6301$, $N_g - N_p = 0.0427$; finally the color changed from green to brown with X = greenish brown, Y = deep brown, Z = dark brown. Except for the color change these modifications are conveniently summarized in their relation to composition in Fig. 281.

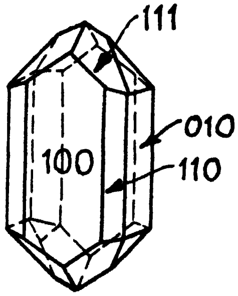

FIG. 280.—A crystal habit of $BaSiO_3 \cdot 6H_2O$.

Hornblende differs from the tremolite-actinolite series chiefly in containing alumina and soda, but crystallographically and optically it is very similar to that series. Also, it is affected in about the same way by heating to 800° C. But in the case of hornblende the effects of heating are still more pronounced; for example, the extinction angle changes from about 20° to sensibly 0°, while the indices may be increased as much as 0.05 and the birefringence may be increased even

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[43] V. E. Barnes: *Am. Mineral.*, XV, 1930, p. 393.

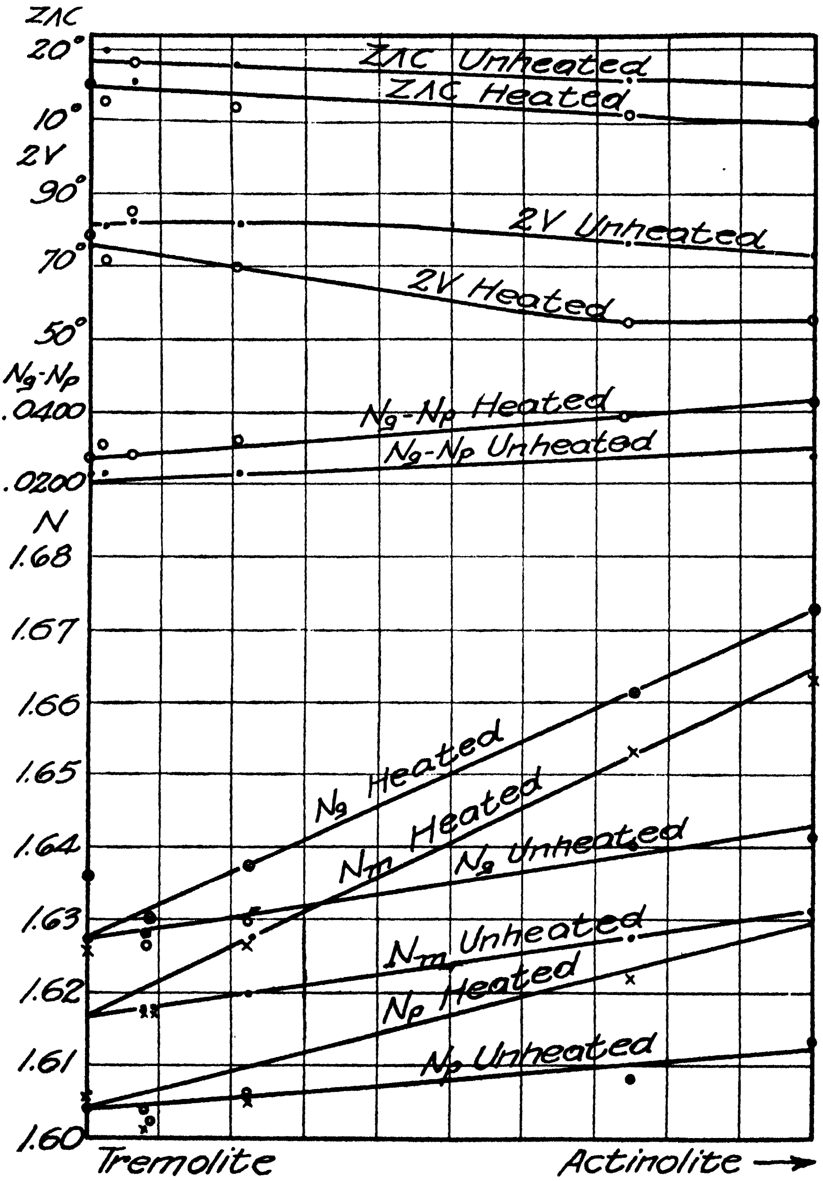

FIG. 281.—Effects on optical properties of heating members of the $H_2Ca_2Mg_7Si_8O_{24}$–$H_2Ca_2Fe_7Si_8O_{24}$ series to about 850° C. (After V. E. Barnes: *Am. Mineral.*, XV, 1930, p. 393.)

more. These changes in relation to the mean index (and therefore approximately in relation to the tenor of iron) are shown in Fig. 282.

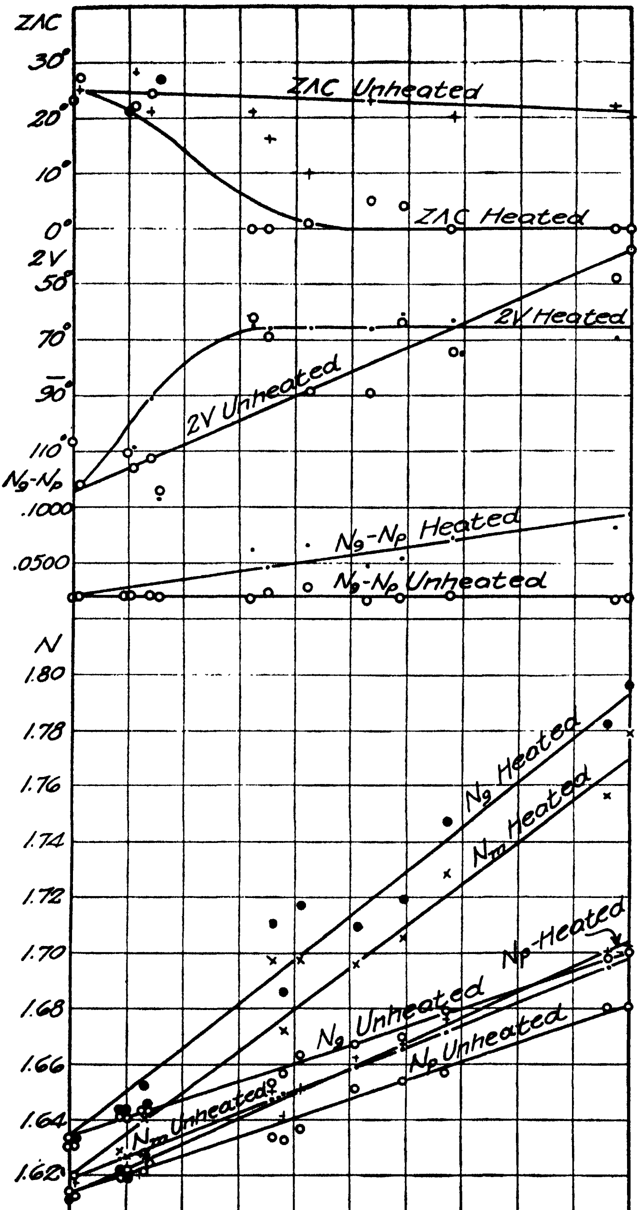

FIG. 282.—Effects on optical properties of heating members of the pargasite-hornblende series to about 850° C. (After V. E. Barnes: *Am. Mineral.*, XV, 1930, p. 393.)

$FeSiO_3 \cdot nH_2O$ is apparently amorphous. G. = 2.8+. Soluble in HCl. Isotropic with N[44] = 1.650–1.654. Color green. Made by mixing solutions of ferrous chloride and sodium silicate. The natural substance, called *greenalite*, is abundant in cherts and taconite of the Lake Superior region.

6. ANHYDROUS SILICATES OF TRIVALENT BASES

$Al_6Si_2O_{13}$ is orthorhombic[45] with $a : b : c = 0.986 : 1 : ?$. Crystals prismatic with distinct 010 cleavage. G. = 3.03. Changes to corundum and liquid at 1810° C. The optic plane is 010; $Z = c$. (+) 2V = 45° to 50°, $N_g = 1.654$, $N_m = 1.644$, $N_p = 1.642$, $N_g - N_p = 0.012$. Colorless, if pure, but often pink or blue[46] and pleochroic with X = Y = colorless, Z = fine blue. Color is due to 1–3 per cent $Fe_2O_3 + TiO_2$ which raises the indices progressively to $N_g = 1.682$, $N_m = ?$, $N_p = 1.661$, $N_g - N_p = 0.021$. Made from fusion. The natural substance, called *mullite*,[47] occurs in fused argillaceous sediments found as inclusions in igneous intrusions. All three of the natural crystal forms of Al_2SiO_5 (namely *sillimanite*, *andalusite* and *kyanite*) change to mullite and liquid when heated to 1545° C.; andalusite and kyanite change at even lower temperatures.[48] In all its physical properties sillimanite is remarkably like mullite; thus, optically it has the optic plane in 010, $Z = c$. (+) 2V = 25°–30°, $N_g = 1.677$–1.684, $N_m = 1.658$–1.662, $N_p = 1.657$–1.661, $N_g - N_p = 0.020$–0.023. Colorless or tinted and pleochroic in pink or blue.

Alumina-silica hydrogels are apparently amorphous[49] and isotropic. After ignition N = 1.48 to 1.68 increasing with increasing alumina, thus: if $Al_2O_3 : SiO_2 = 0 : 1$, N = 1.48–1.485; 1 : 6.5, N = 1.48–1.49; 1 : 4.3, N = 1.495–1.505; 1 : 2.8, N = 1.520–1.535; 1 : 1.9, N = 1.535–1.545; 1 : 0.9, N = 1.58–1.595; 1 : 0, N = 1.68. The determination of the refractive index of the colloidal constituent of clay might be used to determine whether the alumina is present as a hydrate or as a silicate (?).

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[44] As measured at the University of Wisconsin by Dr. J. E. Hawley.

[45] N. L. Bowen and J. W. Greig: *Jour. Am. Ceram. Soc.*, VII, 1924, p. 238.

[46] W. Eitel: *Zeit. anorg. Chem.*, LXXXVIII, 1914, p. 173.

[47] Bowen, Greig and Zies: *Jour. Wash. Acad. Sci.*, XIV, 1924, p. 183. Mullite is said to be merely $2Al_2SiO_5 + Al_2O_3$, that is, extremely fine corundum in fibrous sillimanite, by W. Eitel: *Zeit. Kryst.*, LXIV, 1927, p. 535.

[48] A. B. Peck: *Am. Mineral.*, X, 1925, p. 253.

[49] J. Splichal: *Mineral. Abst.*, I, 1922, p. 288.

7. HYDROUS SILICATES OF TRIVALENT BASES

$H_2Al_2Si_4O_{12}$ (?) is orthorhombic[50] with perfect 001 cleavage and flexible lamellæ. H. = 1–1.5. G. = 2.50. Soluble in HCl. The axis X is normal to the 001 cleavage. N = 1.58, $N_g - N_p = 0.02$ (Becke);[51] $N_g = 1.585$, $N_m = 1.55$, $N_p = 1.533$, $N_g - N_p = 0.052$ (Müller).[50] Colorless. Made in a steel bomb. The natural substance, called *pyrophyllite,* is abundant in some schises. The artificial crystals have not been analyzed.

$H_4Al_2Si_2O_9$ has three crystal phases,[52] all monoclinic. The common phase, known as *kaolinite,* forms vertically elongated vermicular crystals with perfect 001 cleavage. H. = 2–2.5. G. = 2.63. F. = 7. Insoluble in acids. The optic plane and Z are normal to 010; $X \wedge \perp 001 = 2°$. (−) 2V = small, $\rho > v$. $N_g = 1.566$, $N_m = 1.565$, $N_p = 1.561$, $N_g - N_p = 0.005$. Also $N_g = 1.564$, $N_m = ?$, $N_p = 1.556$, $N_g - N_p = 0.006$ (nat. cryst.). An artificial phase, made by heating the constituents in an autoclave[53] at 250 atmospheres for 288 hours, has G. = 2.68, N = 1.56, $N_g - N_p$ = distinct. Colorless. $H_4Al_2Si_2O_9$ begins to dehydrate at 430° C. and the refractive index[54] decreases in rectilinear fashion from 1.568 to 1.535 (which represents a loss of 10 per cent of water); then the index falls more rapidly to 1.464. During this change the mineral has become uniaxial (negative) and has retained its birefringence without change. Such partly dehydrated *kaolinite* has been called *metanacrite* by Rinne.[55] The alumina may be dissolved out of metanacrite with HCl and the remaining silica is negative uniaxial (like the silica skeletons left after treating mica with sulphuric acid) with unimpaired birefringence and a refractive index of 1.440.

8. ANHYDROUS SILICATES OF DIVALENT AND MONOVALENT BASES

Na_2CaSiO_4 is isometric with G = 2.79, F = high, and N nearly = 1.60. Colorless. Made from fusion.

$Na_4CaSi_3O_9$ is isometric[56] and pyritohedral. Crystals octahedrons or more complex forms. G. = 2.775. Isotropic with N =

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[50] J. Koenigsberger and W. J. Müller: *N. Jahrb. Min. Beil. Bd.* XLIV, 1920, p. 402.

[51] F. Becke: *Zeit. anorg. Chem.*, LXXII, 1911, p. 156.

[52] C. S. Ross and P. F. Kerr: *Am. Mineral.*, XV, 1930, p. 34 and 144; *U. S. Geol. Surv. Prof. Pap.* 165, 1931, p. 151.

[53] Van Nieuwenberg and Peters: *Rec. Trav. Chim. Pays Bas*, XLVIII, 1929, p. 27.

[54] K. Spangenberg: *Cent. Min.*, 1926, A, p. 417.

[55] F. Rinne: *Zeit. Kryst.*, LXI, p. 119.

[56] G. W. Morey and N. L. Bowen: *Trans. Soc. Glass Tech.*, IX, 1925, p. 226. See also R. W. G. Wyckoff and G. W. Morey: *Am. Jour. Sci.*, CCXII, 1926, p. 419.

1.571. Decomposes to $Na_2Ca_2(SiO_3)_3$ and liquid at 1141° C. Colorless. Made from fusion.

$K_4CaSi_3O_9$ forms octahedral crystals[56a] which are isotropic with N = 1.572. In X-ray pattern it is not strictly isotropic. Colorless.

$K_2Be_3Si_4O_{12}$ is isometric[57] with G. = 2.531 and N = 1.523; also weakly birefringent like leucite.

Na_2CaSiO_4 is isotropic[56] and probably isometric with N nearly equal to 1.60. G. = 2.79. F. = high. Colorless. Made from fusion.

K_2CaSiO_4 is hexagonal[56a] forming hexagonal bipyramids. F. = 1630° C. Uniaxial positive with $N_o = 1.600$, $N_e = 1.605\pm$, $N_e - N_o = 0.005\pm$. Colorless.

$K_8CaSi_{10}O_{25}$ is hexagonal;[56a] plates have parallel extinction. Uniaxial negative with $N_o = 1.548$, $N_e = 1.537$, $N_o - N_e = 0.011$. Colorless.

$Na_2Ca_2Si_3O_9$ is probably isometric[56] at high temperature, but only pseudocubic at ordinary temperature, with constant twinning diagonal to square sections; extinction highly inclined to twinning line. Twinning often multiple and complex. Inclined extinction suggests biaxial character. Melts at 1284° C. $N_g = 1.599$, $N_p = 1.596$, $N_g - N_p = 0.003$. Colorless. Made from fusion.

$Na_6Be_6Si_{14}O_{37}$ is orthorhombic[57] with G. = 2.552 and $N_g = 1.545$, $N_m = ?$, $N_p = 1.532$, $N_g - N_p = 0.013$ and (+) $2E = 60°$; therefore $N_m = 1.533$ and $2V = 38°$.

$Na_2Ca_3Si_6O_{16}$ is orthorhombic;[56] crystals prismatic. It dissociates to $CaSiO_3$ and liquid at 1045° C. Positive elongation and parallel extinction. (+) $2V = 75°$. $N_g = 1.579$, $N_m = 1.570$, $N_p = 1.564$, $N_g - N_p = 0.015$. Colorless. Made from fusion. Similar acicular devitrification products of glass have been described under the name *rivaite* by Zambonini[58] and under the name *réaumurite* by Lacroix.[59] Rivaite has been described as having the optic plane normal to the elongation and Z normal to the laths. (−) $2V$ = small, $N_m = 1.56$, $N_g - N_p$ = weak. This is probably wollastonite according to Bowen.[60]

[56a] G. W. Morey, F. C. Kracek and N. L. Bowen: *Jour. Soc. Glass Tech.*, XIV, 1930, p. 149. Revised and supplemented by data from G. W. Morey—personal communication from H. E. Merwin, April 2, 1931. Revision includes statement that there is no compound: $K_2O\cdot 2CaO\cdot 6SiO_2$.

[57] P. Gaubert: *Bull. Soc. Fr. Min.*, L, 1927, p. 504.

[58] *Rend. Acc. Napoli*, XVIII, 1912, p. 223. Dana's 3d Appendix.

[59] *Bull. Soc. Fr. Min.*, XXXVIII, 1915, p. 16; also P. Gaubert: *Comp. Rend.*, 1925, p. 1853.

[60] *Am. Mineral.*, VII, 1922, p. 64.

Réaumurite has been described by Gaubert[59] as having parallel extinction and positive elongation, and as being biaxial with N_g = 1.545–1.55, N_p = 1.54, $N_g - N_p$ = weak.

$K_2Ca_3Si_6O_{16}$ has two crystal phases, both orthorhombic.[56a] The high temperature phase forms stout prisms (with highly inclined extinction). (+) 2V = large. N_g = 1.59, N_m = ?, N_p = 1.575, $N_g - N_p$ = 0.015±. The lower temperature phase forms needles and plates with parallel extinction. (−) 2V = ? N_g = 1.57, N_m = ?, N_p = 1.56, $N_g - N_p$ = 0.010±. Colorless.

$K_2Ca_2Si_9O_{21}$ is monoclinic[56a] or triclinic; crystals are prisms and plates with slightly inclined extinction. (−) 2V = large, N_g = 1.535, N_m = ?, N_p = 1.515, $N_g - N_p$ = 0.020. Colorless.

$K_4CaSi_6O_{15}$ is monoclinic[56a] or triclinic; crystals are plates with inclined extinction. (−) 2V = 60° ± 5°. N_g = 1.543, N_m = 1.541, N_p = 1.535, $N_g - N_p$ = 0.008.

9. ANHYDROUS SILICATES OF TRIVALENT AND MONOVALENT BASES

$LiAlSi_2O_6$ has two (or three?) crystal phases. The α-phase[61] is isotropic (?) or tetragonal and positive uniaxial with N = 1.521, $N_g - N_p$ = 0.007, G. = 2.41, F. = 1380° C. The β-phase is monoclinic with N = 1.665, 1.70;[62] G. = 3.17; metastable and inverts to the α-phase at 850° C. and above with a 30 per cent change of volume. This phase in nature is known as *spodumene*; found chiefly in pegmatite.

$LiAlSi_2O_6$ glass has G. = 2.36 and N = 1.519.

$NaAlSiO_4$ has four crystal phases.[63] The high temperature or α-phase is isometric of unknown index, presumably about 1.51; it is stable above 1248° C. and inverts at 687° C. on cooling to a triclinic phase characterized by lamellar complicated twinning with G. = 2.51. (−) 2V = 12°–15°, N_g = 1.514, N_m = 1.514−, N_p = 1.509, $N_g - N_p$ = 0.005. Colorless. The natural substance, called *carnegieite*, is supposed to form a constituent of some plagioclase.[64] The α-phase may show a second inversion at 227° C. marked (on heating) by an abrupt increase in birefringence.

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[61] Ballo and Dittler: *Zeit. anorg. Chem.*, LXXIV, 1912, p. 33, LXXV, p. 68, LXXVI, 1912, p. 48. F. Meissner: *Ibid.*, CX, 1920, p. 187. F. M. Jaeger and A. Simek: *Proc. Akad. Amsterdam*, XVII, 1914, p. 239.

[62] Le Coultre: *Bull. Soc. Chim. Fr.*, XXXIII, 1923, p. 429.

[63] N. L. Bowen and J. W. Greig: *Am. Jour. Sci.*, CCX, 1925, p. 204.

[64] H. S. Washington and F. E. Wright: *Am. Jour. Sci.*, CLXXIX, 1910, p. 64.

The low temperature or β-phase is hexagonal with $c = 0.839$. Crystals short prismatic with poor $10\bar{1}0$ and 0001 cleavages. G. = 2.619. F. = 1526° after inversion at 1248° C. Gelatinizes with acids. Uniaxial negative with $N_o = 1.537$, $N_e = 1.533$, $N_o - N_e = 0.004$. Colorless. This phase of $NaAlSiO_4$ may take $KAlSiO_4$ into crystal solution in large and perhaps unlimited amounts[65] at high temperature with only slight changes in the optic properties. It may take $CaAl_2Si_2O_8$ (or perhaps $CaAl_2O_4 + SiSiO_4$) into crystal solution[66] up to 35 per cent, and this makes no change in N_o and a linear change in N_e from 1.533 to 1.539, the optic sign changing through an isotropic condition at about 23 per cent of the lime molecule. The natural substance, called *nephelite,* is the most important feldspathoid of igneous rocks. $NaAlSiO_4$ glass has N = 1.510.

$LiAlSiO_4$ is finely granular[67] with G. = 2.362 and N = 1.531 Na, $N_g - N_p$ = weak; the glass has G. = 2.429 and N = 1.541 Na. Colorless if pure. Made from fusion. The artificial product is not the same as the natural substance, called *eucryptite,* of the same, or nearly the same, composition, which has $N_o = 1.54$ or 1.545 and $N_o - N_e$ = weak (Larsen).

$K_2Al_2SiO_6$ is isometric;[68] crystals octahedral. Soluble in HCl. Isotropic with N = 1.540. Colorless. Made from fusion.

$KAlSiO_4$ has two crystal phases.[68] The high temperature or α-phase is orthorhombic and stable above 1540° C. F. = 1800° C. At ordinary temperature it is only metastable, but it has been formed at about 500° C. It shows very common twinning of the aragonite type. (−) 2V = 39°, $N_g = 1.536$, $N_m = 1.535$, $N_p = 1.528$, $N_g - N_p = 0.008$. Colorless. Made from fusion. The glass has N = 1.508. Apparently described as occurring in volcanic rocks in West Africa.

The β-phase of $KAlSiO_4$ is hexagonal with $c = 0.837$; isomorphous with nephelite; crystals simple prisms with H. = 6. Uniaxial negative with $N_o = 1.532$, $N_e = 1.527$, $N_o - N_e = 0.005$. The birefringence[69] is not increased by 6.6 per cent Fe_2O_3. Colorless. The natural substance, called *kaliophilite,* is rare in some volcanic rocks. Made with potassium tungstate as a flux at 1300° C., but yields $KAlSi_2O_6$ at 800° C.

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[65] N. L. Bowen: *Am. Jour. Sci.,* CXCIII, 1917, p. 115.

[66] N. L. Bowen: *Am. Jour. Sci.,* CLXXXIII, 1912, p. 551.

[67] F. M. Jaeger and A. Simek: *Proc. Akad. Amsterdam,* XVII, 1914, p. 239.

[68] N. L. Bowen: *Am. Jour. Sci.,* CXCIII, 1917, p. 115. G. W. Morey and N.L. Bowen: *Am. Jour. Sci.,* CCIV, 1922, p. 1.

[69] G. Friedel: *Bull. Soc. Fr. Min.,* XXXV, 1912, p. 471.

$RbAlSiO_4$ is hexagonal[70] and isomorphous with nephelite. Uniaxial negative with $N_o = 1.530$, $N = 1.526$, $N_o - N_e = 0.004$. Colorless.

$NaYSiO_4$ is hexagonal[70] with $c = 0.813$. Uniaxial negative with $N_o = 1.832$, $N_e = 1.804$, $N_o - N_e = 0.028$. Colorless.

$LiLaSiO_4$ is hexagonal[70] and isomorphous with nephelite. Uniaxial negative with $N_o = 1.870$, $N_e = 1.843$, $N_o - N_e = 0.027$. Colorless.

$NaLaSiO_4$ is hexagonal[70] with $c = 0.814$. Uniaxial negative with $N_o = 1.867$, $N_e = 1.840$, $N_o - N_e = 0.027$. Colorless.

$KLaSiO_4$ is hexagonal[70] with $c = 0.814$. Uniaxial and negative with $N_o = 1.867$, $N_e = 1.840$. $N_o - N_e = 0.027$. Colorless.

$NaPrSiO_4$ is hexagonal[70] and isomorphous with nephelite. Uniaxial and negative with $N_o = 1.889$, $N_e = 1.861$, $N_o - N_e = 0.028$. Colorless.

$NaNdSiO_4$ is hexagonal[70] with $c = 0.813$. Uniaxial and negative with $N_o = 1.889$, $N_e = 1.861$, $N_o - N_e = 0.028$. Colorless.

$NaSmSiO_4$ is hexagonal[70] and isomorphous with nephelite. Uniaxial and negative with $N_o = 1.898$, $N_e = 1.867$, $N_o - N_e = 0.031$. Colorless.

$KAlSi_2O_6$ has two crystal phases;[68] the high temperature or α-phase is isometric. Crystals trapezohedral, as in Fig. 283. G. = 2.47. Unstable below about 620° C. Isotropic with[71] $N = 1.495$ at 750° C. and about 1.501 at 20° C. Colorless. Made from fusion. The natural substance, called *α-leucite,* is a feldspathoid found in some volcanic rocks.

The β-phase of $KAlSi_2O_6$ is orthorhombic (?) and characterized by complex multiple twinning as in Fig. 284 by means of which crystals retain an external pseudo-isometric form. (+) $2V$ = very small, $N_g = 1.509$, $N_m = N_p = 1.508$, $N_g - N_p = 0.001$. Colorless. Made from fusion. The natural substance, called β-leucite, is a feldspathoid found in some volcanic rocks.

$KFeSi_2O_6$ has two crystal phases; one, produced with a vanadate flux, is pseudo-isometric[72] and has been called *iron-leucite*; it has[73] G. = 2.59, $N = 1.619$ and $N_g - N_p$ = more than[74] leucite; the other is monoclinic and is called *potassium-aegirite*; it is prismatic, insoluble in HCl; the optic plane is 010; $X \wedge c$ = 0°–2°; (−) 2V = rather large, N_g = ?, $N_m > 1.80 > N_p$, $N_m - N_p = 0.02$–0.03. Color yellowish green with X > Y. Made in a steel bomb.

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[70] G. Trömel: *Ver. K. Wilhelm Inst. Silikatfor.*, III, 1930, p. 103.

[71] F. Rinne and R. Kolb: *N. Jahrb. Min.*, II, 1910, p. 157.

[72] Hautefeuille: *Comp. Rend.*, XC, 1880, p. 313, 378.

[73] P. Gaubert: *C. R. Cong. Soc. Sav. Sci.*, 1925.

[74] P. Niggli: *Zeit. anorg. Chem.*, LXXXIV, 1914, p. 31.

$Na_5Fe(SiO_3)_4$ is hexagonal [75] in prismatic crystals which are slowly attacked by water and gelatinize with HCl. F. = 838° C. Uniaxial and positive with $N_o = 1.609$, $N_e = 1.625$, $N_e - N_o = 0.016$. $Na_5Fe(SiO_3)_4$ glass has N = 1.583.

$6Na_2O \cdot 4Fe_2O_3 \cdot 5SiO_2$ forms [75] rounded grains which fuse at 1091° C. They have $N_m = 1.96$ and $N_g - N_p = 0.01\pm$. They show intricate polysynthetic twinning.

$LiAlSi_4O_{10}$ has two (or three?) crystal phases; at low temperature the natural substance is monoclinic with $a : b : c = 1.154 : 1 : 0.744$, $\beta = 67° 34'$; crystals are commonly 001 or 010 tablets with perfect 001 and distinct 201 cleavages. H. = 6. G. = 2.40. The optic plane and Z are normal to 010; $X \wedge a$ (= 001 cleavage) = −2° to −8°. (+) 2V = 83° 34′ Na. $N_g = 1.516$, $N_m = 1.508$ Li, 1.510 Na, 1.518 blue, $N_p = 1.504$, $N_g - N_p = 0.012$. The natural substance is called *petalite*. It becomes uniaxial at 1000–1100° C. and isotropic at 1200° C. with G. = 2.38; it fuses at 1378° C. to a glass which has G. = 2.29 and N = 1.4946.[76] Crystallization of the glass does not produce petalite.

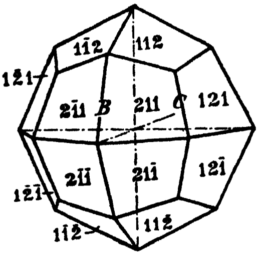

FIG. 283.—A crystal habit of $KAlSi_2O_6$ (leucite).

FIG. 284.—Photomicrograph of $KAlSi_2O_6$ (leucite) showing twinning.

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[75] N. L. Bowen, J. F. Schairer and H. W. V. Willems: *Am. Jour. Sci.*, XX, 1930, p. 405.

[76] A. Brun: *Ann. Sc. Phys. Nat. Genève*, April, 1902, p. 13. Also Ballo and Dittler: *Zeit. anorg. Chem.*, LXXIV, 1912, p. 33; LXXV, p. 68; LXXVI, p. 48.

$NaAlSi_3O_8$ probably has three crystal phases,[77] the high temperature or α-phase is stable above 900° C.; found in nature (called *barbierite*) only in crystal solution in sanidine; by extrapolation the properties may be predicted as follows: (−) $2V = 30° \pm$, $N_g = 1.533 \pm$, $N_m = 1.532 \pm$, $N_p = 1.524 \pm$, $N_g - N_p = 0.009 \pm$. Colorless. It is probably monoclinic and miscible in all proportions *at high temperature* with sanidine, the high temperature phase of $KAlSi_3O_8$. The resulting mix-crystals have optic properties at ordinary temperatures as shown in Fig. 285, which is based on scanty data.

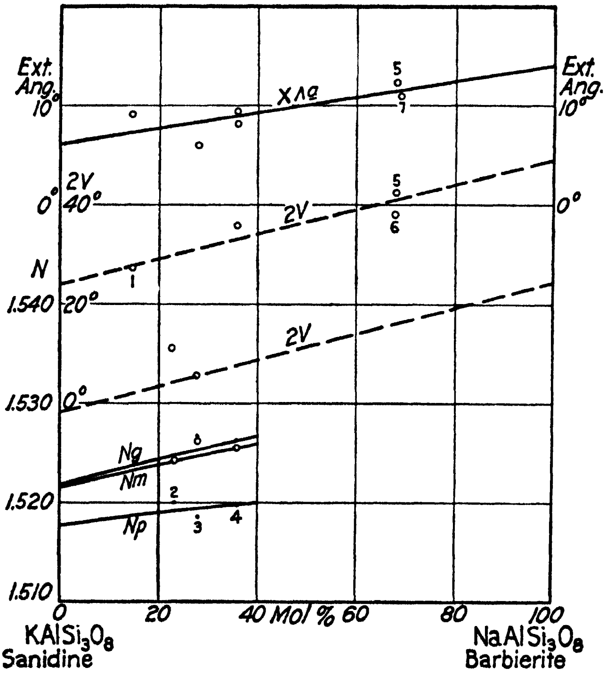

FIG. 285.—Variations in composition and optic properties in the $KAlSi_3O_8$–$NaAlSi_3O_8$ series of monoclinic feldspars; based on scanty data, partly from natural crystals.

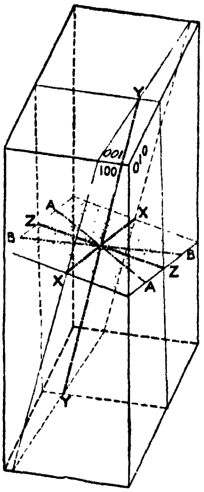

FIG. 286.—Optic orientation of $NaAlSi_3O_8$ (albite).

Below 900° C. the stable phase of $NaAlSi_3O_8$ is triclinic; crystals 010 tablets, etc. G. = 2.605, F. = 1100° C. The optic plane is about normal to 010, Z making an angle of 75° with it. (+) $2V = 70°$, $N_g = 1.5362$ C, 1.5386 D, 1.5445 F, $N_m = 1.5299$ C, 1.5323 D, 1.5381 F, $N_p = 1.5258$ C, 1.5282 D, 1.5341 F, $N_g - N_p = 0.0104$

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[77] A. N. Winchell: *Jour. Geol.*, XXXIII, 1925, p. 714.

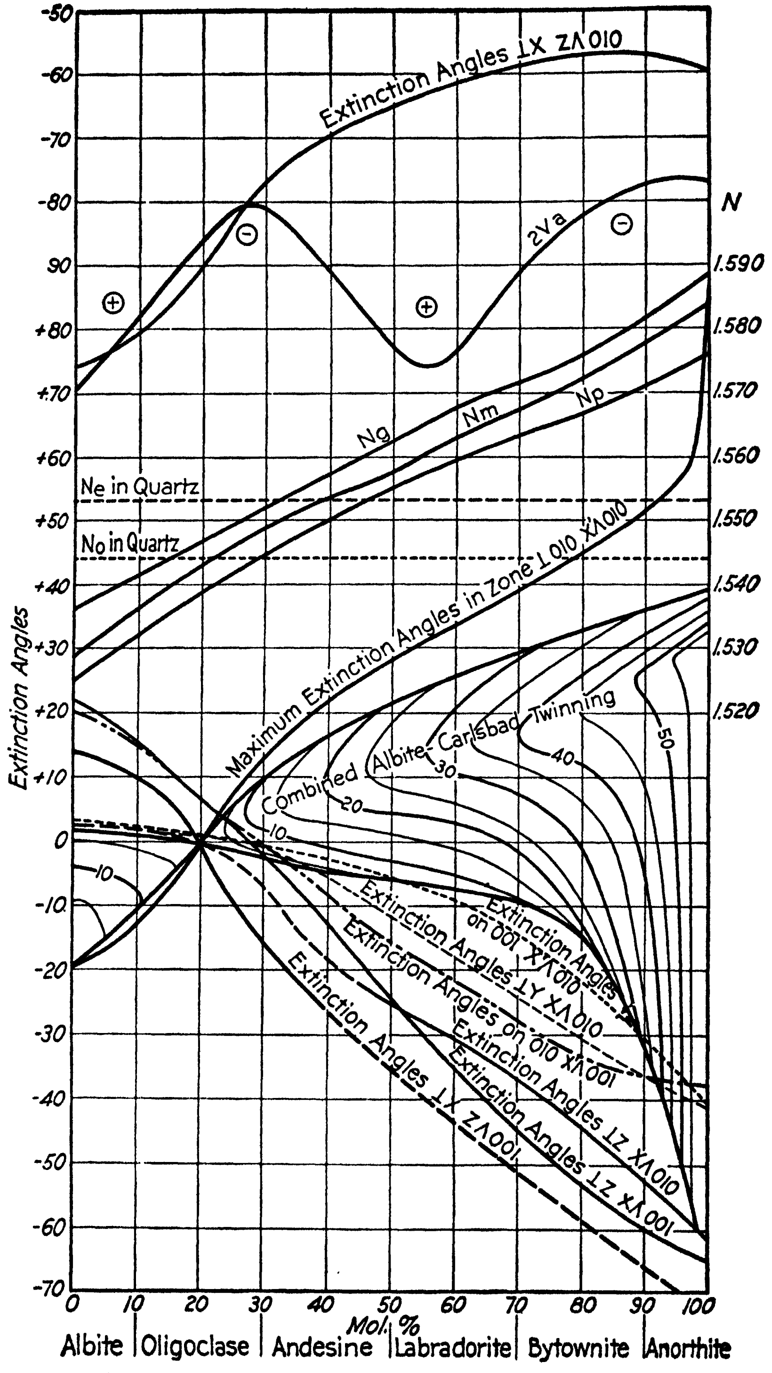

FIG. 287.—Variation in composition and optic properties in the $NaAlSi_3O_8$–$CaAl_2Si_2O_8$ series of triclinic plagioclase feldspars. Based on natural crystals.

D. Extinction angles: normal to X, +77°, normal to Z, +21°, parallel to 001, +3°, parallel to 010, +20°. Colorless. The natural substance, called *albite*, is the pure sodium *feldspar* found in some pegmatite, etc. It is miscible in all proportions with $CaAl_2Si_2O_8$ to form the *plagioclase* series. All parts of this series have been made artificially,[78] but not studied optically with sufficient detail and precision to give data for a graph. The relations shown in Fig. 287 are therefore based on natural crystals.

A metastable phase of $NaAlSi_3O_8$ at low temperature is pseudo-monoclinic and triclinic. This form (*analbite*) [79] has not been made artificially.

$NaAlSi_3O_8$ glass [80] has G. = 2.382 and N = 1.4864 Li, 1.4891 Na, 1.4916 Tl.

$KAlSi_3O_8$ has three crystal phases.[78] The high temperature phase known as *sanidine*,[79] is monoclinic. It is stable above 900° C. and metastable below that temperature. Crystals 010 tablets, etc., with perfect 001 and distinct 010 cleavages. H. = 6. G. = 2.57–2.58. Begins to change to $KAlSi_2O_6$ and liquid at 1170° C. and is completely liquid at 1530° C. Optic properties not yet measured on pure material; by extrapolation they seem to be: the optic plane is 010; $X \wedge a = 6°$, $(-)\ 2V = 0°–20°$, $N_g = N_m = 1.523$, $N_p = 1.517$, $N_g - N_p = 0.006$. Colorless. Made from crystallization of glass at about 1150° C. The natural substance is a common *feldspar* in volcanic rocks. The properties of mix-crystals of sanidine and $NaAlSi_3O_8$ (barbierite) are shown in Fig. 285.

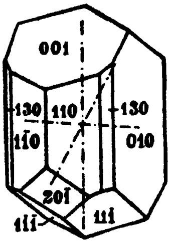

FIG. 288.

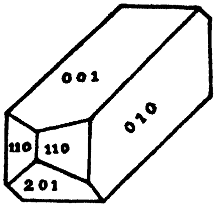

FIG. 289.

FIGS. 288, 289.—Crystal habits of $KAlSi_3O_8$ (orthoclase).

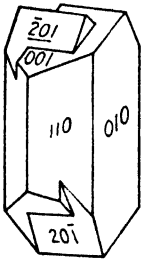

FIG. 290.—A Carlsbad twin of $KAlSi_3O_8$. (orthoclase).

The stable low temperature phase of $KAlSi_3O_8$, known as *adularia* [79] is also monoclinic. It is stable below about 600° C. Crystals short prismatic, etc., with Carlsbad twinning, perfect 001 and distinct 010 cleavages. H. = 6. G. = 2.55. Insoluble in HCl. The optic plane is normal to 010; $X \wedge a = 3°$, $(-)\ 2V = 62°$, $N_g = 1.525$, $N_m = 1.523$, $N_p = 1.519$, $N_g - N_p = 0.006$. Colorless. Made by crystallization in a steel bomb.[81] The natural substance practically always contains

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[78] A. L. Day, E. T. Allen and J. P. Iddings: Isomorphism of Feldspars: *Carn. Inst. Publ.* 31, Washington, 1905.

[79] A. N. Winchell: *Jour. Geol.*, XXXIII, 1925, p. 714. Sanidine was called *abnormal orthoclase* by Des Cloizeaux.

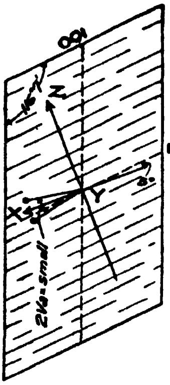

FIG. 291.—Optic orientation of $KAlSi_3O_8$ (sanidine).

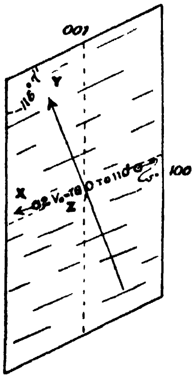

FIG. 292.

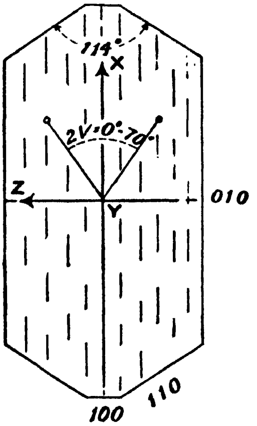

FIG. 293.

FIGS. 292, 293.—Optic orientation of $KAlSi_3O_8$ (adularia)

10–25 per cent $NaAlSi_3O_8$ in crystal solution; it is the common *orthoclase feldspar* of igneous rocks.

Another low temperature phase of $KAlSi_3O_8$, known as *microcline*, is a common triclinic *feldspar*, but has not been produced in pure artificial crystals.

$KFeSi_3O_8$ is monoclinic and triclinic [73] corresponding with orthoclase and microcline. The monoclinic phase shows common twinning on 100, 001 or 021; G. = 2.712; the optic plane is parallel with 010 and extinction in 010 is at 7°–8° to *a*. $N_g = 1.609$, $N_m = ?$, $N_p = 1.601$, $N_g - N_p = 0.008$. Color yellow. Made by passing SiO_2 and Fe_2O_3 into fused potassium vanadate and cooling slowly.

$NaFeSi_2O_6$ is monoclinic [82] in thin 100 plates elongated parallel to *c*; perfect 110 cleavages at 88°. H. = 6–6.5. G. = 3.55 ±. The optic plane is 010; $X \wedge c = +8°$ (red) to $+10°$ (blue). $(-)\ 2V = 62°$ Li,

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[80] E. S. Larsen: *Am. Jour. Sci.*, XXVIII, 1909, p. 263.

[81] J. Koenigsberger and W. G. Müller: *N. Jahrb. Min. Beil. Bd.* XLIV, 1921, p. 402; G. W. Morey and N. L. Bowen: *Am. Jour. Sci.*, CCIV, 1922, p. 1.

[82] H. S. Washington and H. E. Merwin: *Am. Mineral.*, XII, 1927, p. 233.

60° ± Na, 60° (blue); $N_g = 1.836$, $N_m = 1.819$, $N_p = 1.776$, $N_g - N_p = 0.060$. Color yellow to brown or green, and weakly pleochroic. Made from fusion. The natural substance, called *acmite* or *aegirite*, is an uncommon pyroxene. Apparently miscible in all proportions with $CaMgSi_2O_6$ and $CaFeSi_2O_6$, but artificial mix-crystals have not been studied.

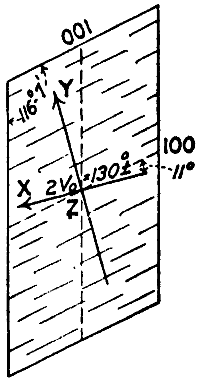

FIG. 294.—Optic orientation of $(K,Na)AlSi_3O_8$ (sodian adularia).

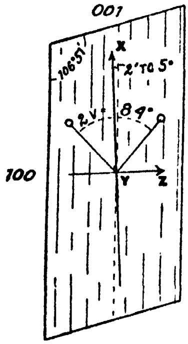

FIG. 295.—Optic orientation of $NaFeSi_2O_6$ (acmite).

10. HYDROUS SILICATES OF TRIVALENT AND MONOVALENT BASES

The substances of this division are nearly all artificial alteration products of natural zeolites. The formulas of the artificial substances are so complicated and questionable that it seems better to avoid them by classifying the substances under the name of the natural zeolite from which they are derived.

Analcite is isometric often in trapezohedral crystals. Somewhat variable in composition, but nearly $NaAlSi_2O_6 \cdot H_2O$. H. = 5. G. = 2.25 ±. F. = 2.5. Gelatinizes with HCl. Isotropic [50] with N = 1.472. Colorless. Made in a steel bomb. Natural analcite increases in birefringence as it loses its water [83] when heated; for example, a crystal with $N_g - N_p = 0.00032$ in its natural state has $N_g - N_p = 0.00072$ after losing 3.6 H_2O, $N_g - N_p = 0.00134$ after losing 6.3 H_2O, and $N_g - N_p = 0.00212$ after losing 8.0 H_2O. However, the birefringence decreases to zero if the mineral is heated to 200°–250° C. in *water vapor*.[84] When heated in air until cloudy and then immersed in oil, analcite is triclinic [85] with negative birefringence and so similar to the high temperature condition of leucite that it has been called *natronleucite*. A single cubic crystal is then composed of many twinned parts.

Gmelinite from Iceland [86] has: (−) 2V = 0°–30° and $N_g - N_p =$

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[83] G. Friedel: *Bull. Soc. Fr. Min.*, XIX, 1896, p. 363.

[84] C. Klein: *Sitz. Akad. Wiss. Berlin*, 1897, p. 290.

[85] F. Rinne: *Sitz. Akad. Wiss. Berlin*, XLVI, 1890, p. 1163.

[86] F. Grandjean: *Comp. Rend.*, CXLIX, 1909, p. 866, and *Bull. Soc. Fr. Min.*, XXXIII, 1910, p. 5.

0.002; dehydrated and saturated with air it has: (+) $2V < 10°$, $N_g - N_p = 0.027$. Saturated with iodine, it is pleochroic with a = clear brown, c = red brown to opaque. Saturated with bromine it is colored, with a = nearly colorless, c = reddish yellow; heated with boiling glycerine it becomes pleochroic with a = colorless, c = red brown.

Gmelinite from Nova Scotia [87] takes up K in place of Na in thirty minutes in contact with potassium mercuric iodide with loss of 4 per cent H_2O and increase of density from 2.045 to 2.090; no optic data given. The change can be reversed by immersion in NaCl solution.

Natrolite which has 2E = 98° 58′ at 15° C. has [88] 2E = 90° 55′ at 307.9° C. at which temperature the water is expelled.[89] However, when natrolite is heated until it is cloudy and then immersed in oil [85] it becomes monoclinic (called *meta-natrolite*), the former 001 becoming 010 and the former prism faces becoming 101 and $\bar{1}01$; in this condition the optic angle and birefringence are not distinctly changed; $Z = b$ and $X \wedge c = 7°$. Metanatrolite reverts easily to natrolite on cooling in moist air.

Natrolite has been changed artificially [90] to Ca-natrolite, K-natrolite, Ag-natrolite, Tl-natrolite and NH_4-natrolite, but the optic properties of these are unknown. The changes are incomplete and proceed more slowly than in zeolites containing more water.

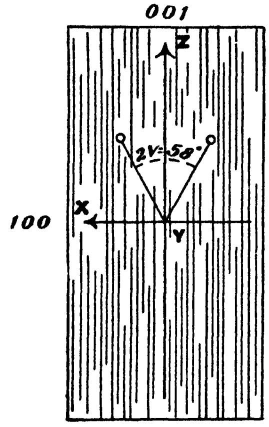

FIG. 296.—Optic orientation of $Na_2Al_2Si_3O_{10} \cdot 2H_2O$ (natrolite).

11. ANHYDROUS SILICATES OF TRIVALENT AND DIVALENT BASES

$Ca_3Al_2Si_3O_{12}$ has been crystallized artificially,[91] but the optic properties were not reported. The natural substance, called *grossularite,* is a common *garnet* which is isotropic or weakly birefringent with N = 1.735 (pure).

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[87] T. L. Walker: *U. Toronto Studies, Geol. Ser.,* 14, 1922, p. 48.

[88] J. Lorenzen: *Zeit. Kryst.,* XVI, 1890, p. 612.

[89] G. Stoklossa: *N. Jahrb. Min. Beil. Bd.* XLII, 1919, p. 33.

[90] I. Zoch: *Chemie der Erde,* I, 1915, p. 219.

[91] E. S. Shepherd, G. A. Rankin and F. E. Wright: *Am. Jour. Sci.,* CLXXVIII, 1909, p. 305.

Calcium aluminum silicate [92] (?), abundant in Portland cement clinker, is uniaxial negative with $N_o = 1.730$, $N_e = 1.726$, $N_o - N_e = 0.004$. Colorless.

$Ca_2Al_2SiO_7$ is tetragonal.[93] Crystals prismatic with distinct 001 cleavage. H. = 6. G. = 3.04. Uniaxial negative with $N_o = 1.669$, $N_e = 1.658$, $N_o - N_e = 0.011$. Colorless. Made from fusion. The natural substance, called *gehlenite*, is quite impure in nearly all cases. $Ca_2Al_2SiO_7$ glass has G. = 2.884 and N = 1.638 Na.

$Ca_2Al_2SiO_7$ is miscible in all proportions with $Ca_2MgSi_2O_7$ as noted on page 285 and illustrated in Fig. 259. According to the writer's interpretation of the experimental work of Buddington, in the light of Berman's study $Ca_2Al_2SiO_7$ is miscible with $CaSi_3O_7$ up to about 14 weight per cent of $CaSi_3O_7$; these mix-crystals have $N_o = 1.643$, $N_e = 1.635$, $N_o - N_e = 0.008$. Similarly, $Ca_2Al_2SiO_7$ is miscible with 14.9 per cent of $CaSi_3O_7$ and 16.1 per cent of $Na_2Si_3O_7$ and these mix-crystals have $N_o = 1.631$, $N_e = 1.614$, $N_o - N_e = 0.016$.

$Ca_2Al_2SiO_7$ with some $Ca_2(Fe,Mn,Mg)Si_2O_7$ and $Na_3Si_2O_7$ has [94] $N_o = 1.6375$ (636), 1.6389 Na, 1.6465 (513), 1.6493 (470), $N_e = 1.6389$ (636), 1.6417 Na, 1.6484 (513), 1.6518 (470), $N_e - N_o = 0.0028$ Na. Another crystal gave: $N_o = 1.6387$ (636), 1.6407 Na, 1.6467 (513), 1.6512 (470), $N_e = 1.6422$ (636), 1.6459 Na, 1.6450 (513), 1.6552 (470), $N_e - N_o = 0.0052$.

$CaLa_2Si_2O_8$ is hexagonal [70] with $c = 0.814$. Uniaxial and negative with $N_o = 1.880$, $N_e = 1.874$, $N_o - N_e = 0.006$. Colorless.

$CaNd_2Si_2O_6$ is hexagonal [70] with $c = 0.813$. Uniaxial and negative with $N_o = 1.903$, $N_e = 1.897$, $N_o - N_e = 0.006$. Colorless.

$Be_3Al_2(SiO_3)_6$ is hexagonal with $c = 0.4989$. Crystals short hexagonal prisms terminated by 0001 or basal plates with indistinct 0001 cleavage. H. = 7.5–8. G. = 2.7. Uniaxial negative with [57] $N_o = 1.580$, $N_e = 1.574$, $N_o - N_e = 0.006$. Colorless when pure; colored light to dark green by addition of a little chromic oxide. The natural substance is called *beryl*—the green variety *emerald*.

$Mg_2Al_4Si_5O_{18}$ has two crystal phases.[32] The high temperature or α-phase is pseudohexagonal and orthorhombic in short prisms stable above 925° to 1150° C. Negative and uniaxial or nearly so. It may take SiO_2(?) in crystal solution causing variation of indices of refraction. From melts with 66 per cent SiO_2 the crystals have $N_g = N_m = 1.522$, $N_p = 1.519$, $N_g - N_p = 0.003$; from melts with 50 per cent SiO_2 they have $N_g = N_m = 1.528$, $N_p = 1.524$, $N_g - N_p = 0.004$. Colorless. Made from fusion. The impure equivalent in nature is probably *cordierite*, which is found especially at contacts.

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[92] J. L. Gillson and E. C. Warren: *Jour. Am. Ceram. Soc.*, IX, 1926, p. 783.

[93] E. S. Shepherd and G. A. Rankin: *Jour. Ind. Eng. Chem.*, III, 1911, No. 4. A. F. Buddington: *Am. Jour. Sci.*, CCIII, 1922, p. 35.

[94] *Cent. Min.*, 1913, p. 631.

At lower temperatures a less stable or μ-phase is produced, which inverts to the α-phase when heated. This phase is fibrous and has an average index of 1.535 from a melt with 68 per cent SiO_2 and of 1.560 from a melt with 40 per cent SiO_2. Colorless. Crystallized from the glass below 925° C.

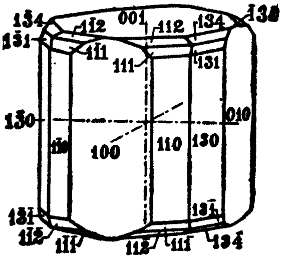

FIG. 297.—A crystal habit of $Mg_2Al_4Si_5O_{18}$ (cordierite).

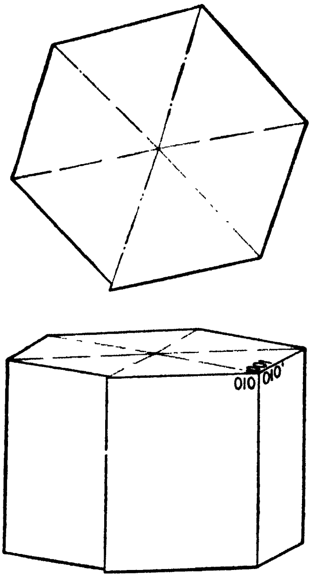

FIG. 298.—Pseudohexagonal cyclic twinning in cordierite.

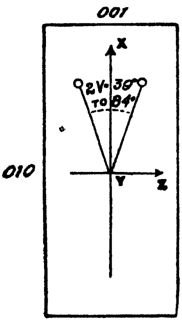

FIG. 299.

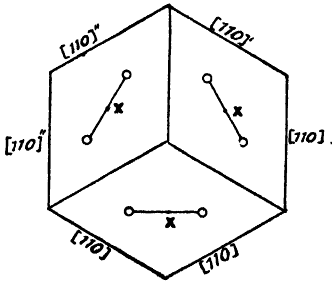

FIG. 300.

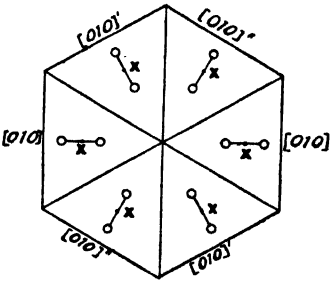

FIG. 301.

FIGS. 299–301.—Optic orientation of cordierite in a simple crystal and in twins.

Calcium aluminum silicate [92] (?), not rare in Portland cement clinker, is biaxial with (+) 2V = about 20°, $\rho < v$ extreme, $N_g = 1.733$, $N_m = 1.720$, $N_p = 1.718$, $N_g - N_p = 0.015$. Found in clusters of small brownish grains, the brown color being perhaps due to an iron stain.

$Ca_3Al_2SiO_8$ is perhaps orthorhombic;[95] it dissociates at 1335° C. to Ca_2SiO_4 and $CaAl_2O_4$. Fibers and grains. Z parallel to fibers. (+) 2V = rather large. $N_g = 1.685$, $N_m = ?$, $N_p = 1.675$, $N_g - N_p = 0.01$. Colorless. Made from glass at about 1300° C.

$BaAl_2Si_2O_8$ is monoclinic and isomorphous with $KAlSi_3O_8$. Crystals 010 plates with common Carlsbad twinning. Distinct 001 and poor 010 cleavages. H. = 6. G. = 3.57 (Fouqué).[96] F. = 1640° ± C. Soluble in HCl. The optic plane is 010; $X \wedge c = +3°$. (+) $2V = 60°–80°$, $N_g = 1.600$,[18] $N_m = 1.593$, $N_p = 1.587$, $N_g - N_p = 0.013$. Colorless. Made from fusion. The natural substance, called *celsian*, is a very rare *feldspar*. $BaAl_2Si_2O_8$ is said to crystallize also in hexagonal plates[97] (at low temperature) which are uniaxial positive.

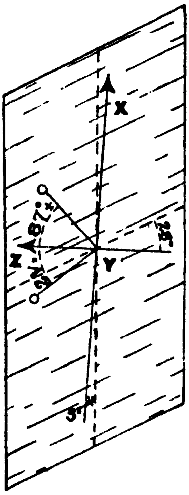

FIG. 302.—Optic orientation of $BaAl_2Si_2O_8$ (celsian).

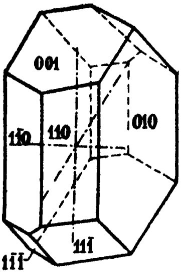

FIG. 303.—A crystal habit of $CaAl_2Si_2O_8$ (anorthite).

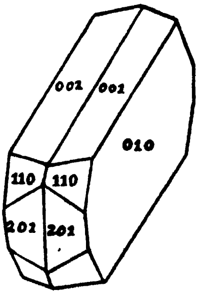

FIG. 304.—A simple albite twin of $CaAl_2Si_2O_8$ (anorthite).

$SrAl_2Si_2O_8$ is supposed to form a complete series[18] of crystal solutions with $CaAl_2Si_2O_8$ and is therefore thought to be triclinic. It is fibrous without twinning. G. = 3.04. $N_g = 1.586$, $N_m = 1.582$, $N_p = 1.574$, $N_g - N_p = 0.012$, (−) 2V = moderate. Colorless.

$CaAl_2Si_2O_8$ is triclinic;[95] crystals 010 tablets or laths. H. = 6. G. = 2.765. F. = 1550° C. Soluble in HCl. Multiple twinning common. The optic plane makes a large angle with 010, the axis being at about 43° to that plane and about 50° to 001, while the axis X makes an angle of about 32° with 010 and about 35° with 001. Extinction angle of 35° on 001 and 37° to 38° on 010; extinction[98] normal to X is at 19½° to 001 and 32° to 010; extinction normal to Z is at 66° to 001 and 52° to 010. (−) $2V = 77°$, $N_g = 1.5885$, $N_m = 1.5832$, $N_p = 1.5755$, $N_g - N_p = 0.013$. Colorless. Made from fusion. The natural substance, called *anorthite*, is an end member of the very common *plagioclase feldspar* series, whose optic properties are shown in Fig. 287 on page 312.

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[95] G. A. Rankin and F. E. Wright: *Am. Jour. Sci.*, CLXXXIX, 1915, p. 1.

[96] *Bull. Soc. Fr. Min.*, III, 1880, p. 124.

[97] A. S. Ginsberg: *Min. Absts.*, II, 1923, 153.

$CaAl_2Si_2O_8$ glass[80] has G. = 2.700 and N = 1.5719 Li, 1.5755 Na, 1.5786 Tl.

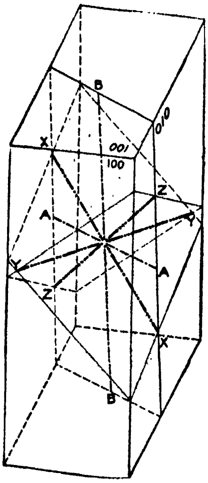

FIG. 305.—Optic orientation of $CaAl_2Si_2O_8$ (anorthite).

12. HYDROUS SILICATES OF TRIVALENT AND DIVALENT BASES (WITH OR WITHOUT MONOVALENT BASES)

The substances of this division are nearly all artificial alteration products of natural zeolites. The formulas of the artificial substances are so complicated and questionable that it seems better to avoid them by classifying the substances under the name of the zeolite from which they are derived.

Chabazite from Aussig[86] with its normal tenor of water has: $X = c$, (−) $2V = 65°$ ±, $N_g - N_p = 0.0014$; after driving out the H_2O and allowing it to absorb dry air the mineral has: (+) $2V$ = less than 12°, $Z = c$, $N_g - N_p = 0.0089$; as it takes up water again the birefringence decreases and the sign changes. Saturated with NH_4OH it is uniaxial positive with $N_g - N_p = 0.004$. Saturated with iodine at 300° C. and cooled in a desiccator it is positive and nearly uniaxial with $N_g - N_p = 0.009$ ± and X = Y = pink, Z = yellow (darker when heated). Saturated with calomel at 500° C. and cooled it is uniaxial negative with $N_g - N_p = 0.045$; the calomel taken up is about 24 per cent and it shatters the crystals. Saturated with Hg at 300° C. and cooled in a desiccator it has: (−) $2V = 74°$, $N_g - N_p = 0.028$ and X = very pale yellow, Y = dark yellow, Z = darker reddish yellow; by addition of water the mineral darkens, X = brown, Y = dark brown, Z = opaque, and the birefringence decreases. The mineral takes up 35 per cent Hg and can then take up 25 per cent H_2O;

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[98] L. Duparc and M. Gysin: *Bull. Soc. Fr. Min.*, XLIX, 1926, p. 63.

upon heating the water goes off and then the mercury, all without destroying the crystal. Saturated with sulphur, the mineral is negative with $N_g - N_p = 0.036$. Saturated with HgS it is positive, pale yellow, $N_g - N_p = 0.036$, and the refringence is increased.

Chabazite, in a section [99] parallel to $10\bar{1}1$, is divided by twinning into two parts along a line parallel with the trace of *c*; the Z′ vibration directions in these parts make angles of about 17° with the twinning line and 35° with each other. Upon heating the crystal these directions gradually change, reaching a maximum of about 55° with the twinning line and 110° with each other, and then decreasing (with a decreasing and then decidedly increasing birefringence) to an angle of about 16° with each other. After partial dehydration such a section will take up CS_2, which causes a very great increase in the birefringence with a change of interference color from gray to higher order white, and changes the Z′ vibration directions to positions at about 85° with the twinning line. After dehydration such a section upon absorbing CO_2 has its Z′ vibration directions at about 110° to each other and has strong birefringence, the plate being nearly normal to an optic axis. Upon absorption of alcohol in place of water the birefringence decreases to zero and then increases again, while the Z′ vibration directions finally reach angles of about 60° with the twinning line; upon absorption of chloroform the results are similar, but the angles are 30°; upon absorption of benzol the angles are 40°; with aniline they are 30°.

Chabazite has been changed [90] artificially to the pure Na compound and then changed back to the pure Ca compound; also to K-chabazite, Ba-chabazite, Ca-Mg-chabazite, Ag-chabazite, Tl-chabazite, Cu-chabazite, and NH_4-chabazite, but optic data regarding these are lacking.

Levynite from Glenarm [86] has: (−) $2V = 0°\text{–}30°$ and $N_g - N_p = 0.0075$; dehydrated and then saturated with dry air it has: (+) $2E = 85°\text{–}120°$, $N_g - N_p = 0.0075$, and N_m is much less than before; saturated with Hg it is biaxial negative with $N_g - N_p = 0.030$ and a = dark red brown to opaque, c = yellow.

Thomsonite, heated until cloudy and then immersed in oil,[85] is still orthorhombic with unchanged optic orientation, but decreased birefringence. In some cases much heating causes the optic plane to become normal to 001.

Thomsonite has been changed artificially [90] to K-thomsonite and Na-thomsonite, but optic data are lacking. At ordinary temperature the change is slow and incomplete.

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[99] F. Rinne: *N. Jahrb. Min.*, 1897, II, p. 28; *Fortsch. Mineral.*, III, 1913, p. 178.

Scolecite, heated until cloudy and then immersed in oil,[85] changes so that 010 becomes 100 and 100 becomes 010. A crystal originally twinned on 100 changes to a twin on the former 010 which is now 100. After heating the birefringence is about the same. X = *b* (the direction that was normal to 100 before heating) and $Y \wedge c = 20° \pm$. By further heating the mineral becomes orthorhombic with the optic plane parallel to 001 and X now normal to 010 which is 100 of the original mineral; in this condition the birefringence is very weak. Crystals do not easily revert to their former condition.

Scolecite has been changed [90] artificially to K-scolecite, Na-scolecite, and NH_4-scolecite. At ordinary temperatures such changes are slower and less complete than in zeolites with more water.

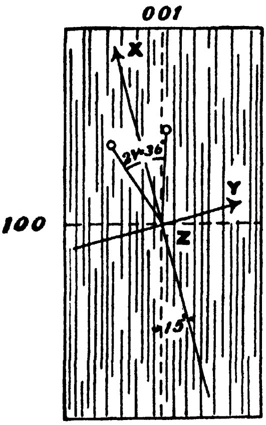

FIG. 306.—Optic orientation of $CaAl_2Si_3O_{10} \cdot 3H_2O$ (scolecite).

Scolecite[100] loses one molecule of water (reversibly) between 160° and 200° C. and is converted into *metascolecite* which has the optic plane and X normal to 010 (= 100 of scolecite) with $Z \wedge c = 70°–75°$; it is optically negative with $2V = 65°$, $\rho < v$; 110 cleavage flakes have positive elongation and an optic axis is inclined about 20° to them. Scolecite loses the remaining two molecules of water between 335° and 345° C. irreversibly; the anhydrous substance has $Z \wedge c = 85°–88°$, $(-)\ 2V = 65°$, $\rho < v$, much weaker birefringence and higher refringence with $N_m = 1.541$. The crystal structure breaks down at about 550° C.

Mesolite[100] is monoclinic and elongated parallel to *b*; it loses half its water content (reversibly) at about 250° C. and the remainder at about 350° C. irreversibly; it is then called *metamesolite* and has its optic plane parallel to the elongation, while a negative bisectrix emerges slightly inclined to one of the cleavages. The crystal structure breaks down at about 670° C.

Laumontite has been changed artificially[101] to Na-laumontite and to K-laumontite in several different ways, but optic data are lacking.

[100] A. Cavinato: *Mem. Accad. Lincei Roma,* II, 1927, p. 320; *Min. Abst.,* IV, 1930, p. 320.

[101] J. Lemberg: *Zeit. Dtsch. Geol. Ges.,* XXXV, 1883, p. 613, and XXXVII, p. 984.

Leonhardite may be a laumontite changed in nature by replacement of two-thirds of its Ca by K and Na. It is optically similar to laumontite, but precise data are lacking. It is stable even when heated.

Gismondite upon heating becomes orthorhombic with (−) $2V$ = small, $X = c$, $N_g - N_p$ = weak. After dehydration crystals will take up mercury [86] which causes little change of optic properties, but if they are then exposed to moisture the mercury changes its condition, the mineral darkens and becomes pleochroic with one direction gray, yellow or colorless and the other direction bluish black, like ink, or purple.

Phillipsite, heated until cloudy and then immersed in oil,[85] has the extinction angle ($Z \wedge c$) in 010 changed from 19° to 9° with no other modification of the optic properties; in moist air the change is not reversed. By further heating the birefringence is decreased distinctly, X and Z exchange places, the extinction angle ($X \wedge c$) changes to 17° in the acute angle β, the optic sign changes to negative and the optic angle changes to almost zero.

Harmotome, originally having (+) $2V = 75°$, after dehydration [86] at 400° C. and cooling in a desiccator has: (−) $2E = 78°$, optic plane 010, lowered refringence, and $N_g - N_p = 0.026$; upon rehydration the extinction angles change. Saturated with mercury vapor and then cooled the mineral can scarcely be distinguished from the dehydrated condition, but if exposed to moisture the mercury changes its state, the mineral darkens and becomes pleochroic with *a* and *c* blue black or purple and *b* clear gray, yellow or colorless.

Harmotome, heated until cloudy and then immersed in oil,[85] has its optic plane changed in position, so that $X \wedge a = \pm 25°$, and also has its birefringence much increased. It is said to be triclinic.

Epistilbite, heated until cloudy and then immersed in oil,[85] becomes orthorhombic with $X = b$ and $Y = a$; in an intermediate condition the mineral must be uniaxial. Upon reabsorption of water the mineral reverts to the original condition.

Stilbite, heated until cloudy and then immersed in oil,[85] becomes orthorhombic with 100 as the optic plane [102] and $Z = c$, but this is accomplished only after a long series of changes, as follows:

Stilbite "with $6H_2O$" (normal H_2O tenor) is monoclinic with $X \wedge c = -5°$, (−) $2V = \pm 30°$ in 010. By gradual loss of water the extinction angle and optic angle both decrease to 0° and the mineral is uniaxial negative with X = *c* at about 125° C. with about 5 H_2O. By further loss of water on heating, $X \wedge c$ gradually increases to +5° and the optic angle becomes gradually larger in a plane normal to 010, passes 90° with change of sign and becomes 0° about Z (= *b*) with X = *c* at about 150° C. with about $4H_2O$. By further loss of water on heating, Y (the direction formerly X) gradually moves from *c* to $Y \wedge c$ = 3°–7°, the optic angle opens about Z (= *b*) in a plane normal to 010, passes 90° with a second change of sign and becomes 0° about X (= *a*) at about 185° C. with about $3H_2O$. By further heating, Z (the direction formerly Y) moves toward *c* until $Z \wedge c$ = 0°, the optic angle opens about X (which is in the obtuse angle β at 83° to 87° with *c*) in 010, passes 90° with a third change of sign and becomes 0° about Z (= *c*). This is the fourth uniaxial condition; it occurs at about 250° C. with about $2H_2O$. The mineral is now orthorhombic. With further heating, the birefringence gradually decreases; with about $1H_2O$ at about 350° C. the mineral is still orthorhombic; with further heating, it becomes microscopically isotropic. All these changes can be produced by dehydration in H_2SO_4 without heating. After complete dehydration the process is not reversible.

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[102] Orientation of Tschermak (*Sitz. Akad. Wiss. Wien.*, CXXVI, 1917, p. 600) in which 100 = Dana's 001, 010 = Dana's 010, 101 = Dana's 100, 001 = Dana's $\bar{1}01$, etc.

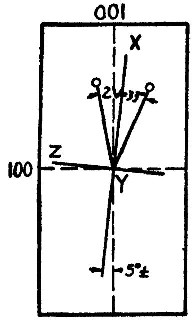

FIG. 307.—Optic orientation of stilbite.

Stilbite can be changed artificially[90] by exchange of bases into pure Ca-stilbite, Na-stilbite, K-stilbite, NH_4-stilbite, Ba-stilbite, Ag-stilbite, and Cu-stilbite. Precise optic data on these substances are lacking, but after immersion in KCl solution for 24 hours at 180° C. stilbite[50] has: $N_g = 1.483$, $N_m = 1.481$, $N_p = 1.478$, $N_g - N_p = 0.005$, $X \wedge c = 6°$; these data must apply to K-stilbite. Also NH_4-stilbite is nearly isotropic and the extinction angle in 010 is nearly 0°. When silver replaces calcium in stilbite the birefringence decreases, but not as much as in the case of NH_4. Na-stilbite is as strongly birefringent as the natural mineral. Cu-stilbite is bluish green.

Heulandite "with $6H_2O$" (normal tenor of H_2O) from Iceland has: (+) 2V = moderate, Z = *b*, $X \wedge a$ = +19° at 20° C.; according to Rinne[85] it changes rapidly with increasing temperature so as to become positive and uniaxial at 80° C. with about $5H_2O$; then X and Y change places, the optic angle (formerly in a plane nearly parallel to 001) opening in a plane nearly parallel to 100, passing through 90° with change of sign and becoming uniaxial negative (with X = *c*)

at about 180° C.; the extinction angle measured to *a* meanwhile gradually decreases, becoming 0° at 150° C. " with $4H_2O$ " so that the mineral is orthorhombic above 150° C. With further heating, the optic angle (formerly in a plane parallel to 100) opens in a plane parallel to 010 (Y and Z having changed places), passes 90° with a second change of sign and becomes uniaxial positive (with $Z = a$) at about 280° C. "with $2H_2O$." With further heating, the optic angle (formerly in a plane parallel to 010) opens in a plane parallel to 001. Above 350° C. a second orthorhombic form exists with weaker birefringence.

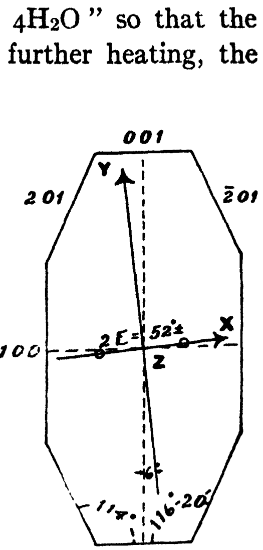

FIG. 308.—Optic orientation of $CaAl_2Si_6O_{16} \cdot 5H_2O$? (heulandite).

Heulandite from Iceland has: (+) 2E = 74° 38′, $Z = b$ and $X \wedge a = +20°\pm$ at ordinary temperature; according to Slawson[103] the uniaxial condition reported by Rinne[85] and Des Cloizeaux[104] is only apparent, the mineral being biaxial with $Z = b$ at all temperatures. The mineral seems to be uniaxial in some cases because the optic plane rotates through the position of the black cross. The relation between temperature, optic angle and rotation of optic plane from the position at ordinary temperature is about as follows, as derived from Slawson's curves:

Temp. C.	2E	Rotation
25°	74° 38′	0°
100°	80°	10°
150°	66°	13°
200°	34°	45°
250°	61°	96°
300°	120°	114°

These observations are in direct conflict with the data of Rinne, not only as to uniaxial condition, but in various other respects.

Gaubert[105] has studied the mineral further. He finds that the optic properties are influenced by three different factors, namely, " optic anomalies " (probably due to variations in composition), temperature, and tenor of water. Change in temperature from 0° to 109° C. without change in tenor of water causes a rotation of the optic plane with increase in the optic angle. Loss of water without change of temperature causes a decrease of the optic angle, the mineral becoming about uniaxial with a loss of 1.8 per cent H_2O (= $\frac{1}{2}H_2O$); with a loss of 2.2 per cent H_2O the optic angle is about 20° in a plane normal to the original position; with a loss of 3 per cent H_2O the optic angle is very large in the new plane.

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[103] C. B. Slawson: *Am. Mineral.*, X, 1925, p. 305.

[104] *Manuel de Minéralogie*, I, 1862, p. 425.

[105] *C. R.* 187, 1928, p. 1057.

Heulandite at 230° C. has indices[106] as follows: $N_g = 1.4747$, $N_m = 1.4733$, $N_p = 1.4651$, $N_g - N_p = 0.0096$.

Heulandite on cooling to $-79°$ C. in liquid air[107] suffers changes so that the optic angle decreases nearly to zero and the optic plane turns so as to become nearly parallel with 001.

Heulandite can be changed artificially[108] to K-heulandite, Ca-heulandite, NH_4-heulandite, etc., but optic data are lacking.

Heulandite heated in boiling glycerine[106] and then plunged into methylene iodide has: G. = 2.19, (+) 2V = 46°, $N_g = 1.5078$, $N_m = 1.5015$, $N_p = 1.5004$, $N_g - N_p = 0.0074$. Heated in the same way and plunged into acetylene tetrabromide it has: G. = 2.16, $N_g = 1.5071$, $N_m = 1.5009$, $N_p = 1.4994$, $N_g - N_p = 0.0077$.

13. COMPOUNDS CONSISTING OF SILICATES WITH SALTS OF OTHER ACIDS

$3CaAl_2Si_2O_8 \cdot CaCO_3$ has been made artificially[91] by crystallizing glass of that composition in a steel bomb with a 10 per cent NaCl solution, but optic data are lacking. The natural substance, called *meionite*, is tetragonal.

$3NaAlSiO_4 \cdot CaCO_3$ is hexagonal[109] prismatic. It forms a eutectic with $CaCO_3$ at 1190° C. and melts at 1253° C. under 65 kg. pressure. Uniaxial negative with $N_o = 1.550$, $N_e = 1.519$, $N_o - N_e = 0.031$. Colorless. The natural mineral known as *cancrinite* is probably closely related to this substance, and is probably stable only under pressure.

$2Ca_2SiO_4 \cdot CaCO_3$ has two crystal phases.[110] The high temperature or α-phase is stable above 1200° C. under pressure of 90 atmospheres. It is orthorhombic with good 001 and 010 cleavages. Optic plane is 100. 2V = large. $N_g = 1.680$, $N_m = ?$, $N_p = 1.665$, $N_g - N_p = 0.015$. Colorless. It forms a eutectic with $CaCO_3$ at 1172° C.

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[106] P. Gaubert: *Bull. Soc. Fr. Min.*, XXX, 1907, p. 104.

[107] Panichi: *Mem. Accad. Lincei*, IV, 1902, p. 389; *Zeit. Kryst.*, XL, 1905, p. 86.

[108] E. Loewenstein: *Zeit. anorg. Chem.*, LXIII, 1909, p. 80.

[109] W. Eitel: *N. Jahrb. Min.*, II, 1922, p. 45. $CaCO_3$ may be replaced in part by Na_2CO_3 (or $NaHCO_3$?); with Ca : Na = 1 : 1, $N_o = 1.525$, $N_e = 1.505$. W. Eitel: *Die Feldspathvertreter*, 1925, p. 232.

[110] W. Eitel: *N. Jahrb. Min. Beil. Bd.* XLVIII, 1923, p. 63.

The β-phase is monoclinic (?) with distinct 001 and poor 100 cleavages at 79°. Optic data on the artificial substance are lacking. The natural substance, called *spurrite*, occurs in a contact zone; very rare.

14. SILICEOUS GLASSES

The index of refraction of many glasses produced by chilling substances of definite composition from the liquid state has been given in preceding pages in connection with the description of the crystal phases. However, no kind of commercial glass corresponds with any of these substances of definite composition, although such glass varies widely in composition. The refractive index and dispersion of glass are very important in connection with its use for optical purposes; they are definitely related to the composition of the glass, and these relationships are of special interest in the microscopic examination of glass.

Silica (SiO_2) seems to be the characteristic, if not the essential, constituent of all commercial glasses, although in certain rare types it may be replaced partly or wholly by B_2O_3 or P_2O_5. The other constituents vary both in kind and in tenor in the various types of glass. For example, in ordinary " crown " glass (= ordinary window glass—type 1), the other constituents are chiefly Na_2O, CaO, and K_2O in variable proportions, in flint glass (also called strass—type 2) the other constituents are chiefly PbO, Na_2O, and K_2O in variable proportions. Glasses of these two types have been known for many years; recently several other types of glass have been coming into use, including especially: type 3, opal glass, containing the constituents of type 1 with also CaF_2, SnO_2 or P_2O_5; type 4, borosilicate crown glass containing the constituents of type 1 with also B_2O_3; type 5, barium glasses containing the constituents of either type 1 or type 2 with also BaO; type 6 (not yet in use) thallium flint glass containing chiefly SiO_2 PbO, and Tl_2O with or without K_2O. Many other types are known, including borate glasses, phosphate glasses, etc., but the types listed are the most important at present.

While glass may be made of nearly any composition, commercial (including optical) glass is much more restricted in composition. In fact all kinds of flint glass are analogous chemically [111] to a two-component series varying from $K_2O \cdot 6SiO_2$ to $PbO \cdot SiO_2$. Strangely enough, when any other oxide replaces an oxide in these two substances, it must do so, not in equal molecular amount, but in equal tenor by weight. For example, when Na_2O replaces K_2O completely, the composition of the first member of the series becomes approximately $Na_2O \cdot 4SiO_2$, because Na_2O is only about two-thirds as heavy as K_2O. Similarly, when CaO or BaO replaces PbO, weight equivalents are involved. Therefore, the composition of all kinds of commercial glass can be expressed approximately on a ternary diagram as shown in Fig. 309. The reasons[111] why commercial glasses are of so limited a range in composition are to be found in the fact that mixtures richer in SiO_2 are very viscous and melt at such high temperatures that they can not be converted into glass in furnaces of the ordinary type, while mixtures richer in alkalies than those shown in the diagram produce glasses which are soft and hygroscopic, and those richer in lead oxide tend to crystallize easily. In other words all com-

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[111] F. E. Wright: Optical Glass: *U. S. Ord. Dept. Doc.*, 2037, 1921.

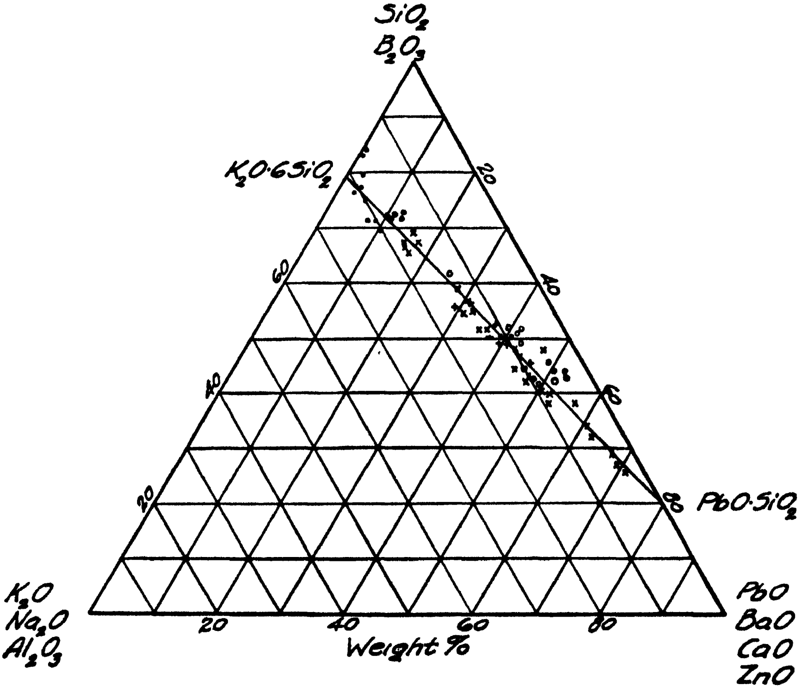

FIG. 309.—Composition of boro-silicate crown glasses (·), ordinary glasses (o), barium crown glasses (O), flint glasses (×), and barium flint glasses (+); also the line connecting $K_2O \cdot 6SiO_2$ and $PbO \cdot SiO_2$. After F. E. Wright: *Ord. Dept. Doc.* 2031, 1921, p. 70.

mercial silicate glasses are of the compositions shown because those are the compositions which melt readily, are not hygroscopic and do not crystallize easily during cooling.

The diagram (Fig. 309) gives a summary of the composition of commercial glasses, but does not express all the facts. If the percentage of silica exceeds 75 per cent, the melt is too viscous to be satisfactory in the furnace; if the alkalies exceed 20 per cent, the glass produced is soft, hygroscopic and chemically unstable, being more or less soluble in water. Accordingly, a minimum of about 5 per cent of lime (or RO) is needed to give a satisfactory melt and durable glass; other things being equal glass with both alkalies is more durable than glass with either alkali alone; if the lime exceeds 13 per cent the mixture fuses difficultly and the resultant glass crystallizes very easily; lead oxide may be used up to 80 per cent, but as the percentage of lead oxide increases, so also do the danger of crystallization on cooling, the danger of attack on the melting pot, the softness of the resultant glass and the depth of its (yellow) color. In the new types of glass barium oxide may be used up to about 50 per cent, but with important percentages of BaO it is desirable to use increasing amounts of B_2O_3 and Al_2O_3; mixtures high in BaO attack the crucible seriously, especially if any free silica is present in the clay. Boron oxide may be used up to about 20 per cent, but is not desirable in lead glasses. Zinc oxide in excess of about 12 per cent is apt to induce crystallization, though small amounts may aid in preventing crystallization. More than 5 per cent of alumina tends [111] to make most glass melts exceedingly viscous, but alumina decreases the danger of crystallization and renders the glass tough and resistant; in dense barium glasses alumina even up to 10 per cent aids in preventing crystallization of barium disilicate and improves the working qualities of the melt and the glass.

Various types of manufactured glass are, in general, so complicated in composition that it is very difficult to draw accurate conclusions regarding the relations between composition and physical properties from analyses of such types accompanied by measures of physical data. Peddle [112] adopted a different method of determining these relationships. He made many kinds of glass of varying, but simple, composition; in any one series the (ratio) composition was varied as to only one component: by measuring the indices of refraction and densities of the glasses thus made, he was able to reach important conclusions. He began with the simplest case: glasses of the composition $100SiO_2 \cdot xNa_2O$, x varying from 20 to 100 molecules. He tested next the corresponding case: $100SiO_2 \cdot xK_2O$, x again varying from 20 to 100 molecules; in this case no large pieces of glass could be obtained and all the glasses were highly soluble in water—physical data could not be measured on them, but were obtained in two cases by extrapolation from other series. The next test was on a series: $100SiO_2 \cdot x/2Na_2O \cdot x/2K_2O$, x varying as before; these glasses were intermediate in character between those of the Na_2O and the K_2O series, but not suitable for measurements of physical data; indices of refraction and density for two melts were obtained by extrapolation from other series. After this preliminary study, Peddle limited his attention to glasses having only two silica-alkali ratios; namely, $100SiO_2 \cdot 40Na_2O$ or K_2O and $100SiO_2 \cdot 20Na_2O$ or K_2O, and studied next the six alkali calcium series: $100SiO_2 \cdot 40Na_2O \cdot xCaO$, $100SiO_2 \cdot 20Na_2O \cdot xCaO$, $100SiO_2 \cdot 40K_2O \cdot xCaO$, $100SiO_2 \cdot 20K_2O \cdot xCaO$, $100SiO_2 \cdot 20Na_2O \cdot 20K_2O \cdot xCaO$, and $100SiO_2 \cdot 10Na_2O \cdot 10K_2O \cdot xCaO$, x varying from 5 to 40 molecules. He studied also four similar series of alkali lead glasses and six similar series of alkali barium glasses. Some of the most important of his results may be tabulated as follows:[113]

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[112] *Jour. Soc. Glass Tech.*, IV, 1920, pp. 3–106, 225–248, 299–366.

SODIUM GLASSES—$100SiO_2 \cdot xNa_2O$

	Weight percentage						
x	SiO_2	Na_2O	$Al_2O_3+Fe_2O_3$	N_D	N_F-N_C	$\nu=\frac{N_D-1}{N_F-N_C}$	Sp. Gr.
20	83.00	16.58	0.42	1.4851	.00790	61.4	2.353
30	76.64	22.98	0.38	1.4952	.00835	59.3	2.413
40	71.20	28.44	0.36	1.5015	.00875	57.3	2.457
70	58.68	41.03	0.29	1.5118	.00962	53.2	2.535
100	49.91	49.84	0.25	1.5168	.01017	50.8	2.560

POTASSIUM GLASSES (by extrapolation)—$100SiO_2 \cdot xK_2O$

	Weight percentage						
x	SiO_2	K_2O	$Al_2O_3+Fe_2O_3$	N_D	N_D-N_C	$\nu=\frac{N_D-1}{N_F-N_C}$	Sp.Gr.
20	76.00	23.60	0.40	1.4937	.00809	61.2	2.388
40	61.27	38.44	0.29	1.5073	.00888	57.1	2.465

SODIUM POTASSIUM GLASSES (by extrapolation)—$100SiO_2 \cdot x/2Na_2 \cdot x/2K_2O$

20	.....	.....	....	1.4892	.00803	60.9	2.377
40	.....	.....	....	1.5044	.00882	57.15	2.472

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[113] Peddle's analyses are all of the "batch" composition; the composition of the resultant glass is slightly different on account of volatilization and pot attack; more accurate data are very scanty.

Wright has shown that the compositions of all commercial glasses correspond approximately with those derivable from a binary series from $K_2O \cdot 6SiO_2$ to $PbO \cdot SiO_2$. If the alkali is soda the series is $Na_2O \cdot 4SiO_2$ to $PbO \cdot SiO_2$. The combination of both alkalies is better than either alone; therefore the series may be regarded as $R_2O \cdot 5SiO_2$ to $PbO \cdot SiO_2$, R standing for both K and Na in approximately equal amounts. This ratio of 1 to 5 for alkalies to silica is exactly the same as Peddle's $100SiO_2$ to $20R_2O$. Accordingly, attention may be concentrated on his results for this ratio.

SODIUM CALCIUM GLASSES—$100SiO_2 \cdot 20Na_2O \cdot xCaO$

	Weight percentage								
x	SiO_2	Na_2O	CaO	$Al_2O_3 + Fe_2O_3$	N_C	N_D	N_F	$N_F - N_C$	$\nu = \frac{N_D - 1}{N_F - N_C}$	Sp.Gr.
5	79.90	15.97	3.73	0.40	1.49455	1.4970	1.50270	.00815	61.98	2.412
10	77.03	15.39	7.19	0.39	1.50628	1.5088	1.51469	.00841	60.50	2.458
15	74.37	14.85	10.41	0.37	1.51662	1.5192	1.52527	.00865	60.03	2.499
20	71.86	14.36	13.42	0.36	1.52526	1.5279	1.53414	.00888	59.44	2.537
30	67.36	13.44	18.86	0.34	1.54074	1.5435	1.55008	.00934	58.20	2.603
40	63 37	12.67	23.65	0.31	1.54443	1.5573	1.56423	.00980	56.87	2.659

POTASSIUM CALCIUM GLASSES—$100SiO_2 \cdot 20K_2O \cdot xCaO$

	Weight Percentage									
x	SiO_2	K_2O	CaO	$Al_2O_3 + Fe_2O_3$	N_C	N_D	N_F	$N_F - N_C$	$\frac{N_D - 1}{N_F - N_C}$	Sp. Gr.
5	73.21	23.01	3.42	0.36	1.49862	1.5011	1.50690	.00828	60.5	2.420
10	70.79	22.75	6.61	0.35	1.50557	1.5081	1.51403	.00846	60.1	2.450
15	68.53	21.54	9.59	0.34	1.51252	1.5151	1.52117	.00865	59.6	2.478
20	66.40	20.87	12.40	0.33	1.51968	1.5223	1.52851	.00883	59.2	2.505
30	62.53	19.65	17.51	0.31	1.53278	1.5355	1.54200	.00922	58.1	2.555
40	59.08	18.57	22.06	0.29	1.54629	1.5491	1.55587	.00958	57.3	2.601

SODIUM POTASSIUM CALCIUM GLASSES—$100SiO_2 \cdot 10Na_2O \cdot 10K_2O \cdot xCaO$

	Weight Percentage										
x	SiO_2	Na_2O	K_2O	CaO	$Al_2O_3 + Fe_2O_3$	N_C	N_D	N_F	$N_F - N_C$	$\nu = \frac{N_D - 1}{N_F - N_C}$	Sp. Gr.
5	76.21	7.87	11.98	3.56	0.38	1.49673	1.4992	1.50496	.00823	60.65	2.415
10	73.59	7.60	11.56	6.88	0.37	1.50608	1.5086	1.51451	.00843	60.33	2.450
15	71.15	7.35	11.18	9.96	0.36	1.51512	1.5177	1.52377	.00865	59.83	2.485
20	68.88	7.12	10.81	12.85	0.34	1.52267	1.5253	1.53151	.00884	59.42	2.523
30	64.71	6.69	10.17	18.11	0.32	1.53736	1.5401	1.54664	.00928	58.20	2.585
40	61.02	6.31	9.59	22.78	0.30	1.54997	1.5528	1.55963	.00966	57.22	2.626

Sodium Lead Glasses—$100SiO_2 \cdot 20Na_2O \cdot xPbO$

	Weight percentage									
x	SiO_2	Na_2O	PbO	Al_2O_3 $+Fe_2O_3$	N_C	N_D	N_F	$N_F—N_C$	$\frac{N_D-1}{N_F-N_C}$	Sp. Gr.
5	71.91	14.38	13.35	0.36	1.51571	1.5186	1.52561	.00990	52.38	2.628
10	63.44	12.69	23.55	0.32	1.54135	1.5448	1.55326	.01191	45.74	2.911
15	56.76	11.35	31.61	0.28	1.56520	1.5691	1.57871	.01351	42.12	3.152
20	51.34	10.27	38.14	0.25	1.58869	1.5930	1.60365	.01496	39.64	3.368
30	43.12	8.62	48.04	0.22	1.62215	1.6272	1.63982	.01767	35.50	3.390
40	37.17	7.43	55.21	0.19	1.65147	1.6571	1.67131	.01984	33.12	3.940

Potassium Lead Glasses—$100SiO_2 \cdot 20K_2O \cdot xPbO$

	Weight percentage									
x	SiO_2	K_2O	PbO	Al_2O_3 $+Fe_2O_3$	N_C	N_D	N_F	N_F-N_C	$\nu=\frac{N_D-1}{N_F-N_C}$	Sp. Gr.
5	66.55	20.81	12.31	0.33	1.51710	1.5201	1.52739	.01029	50.53	2.616
10	59.25	18.52	21.94	0.29	1.54452	1.5480	1.55652	.01200	45.67	2.849
15	53.40	16.69	29.65	0.26	1.56674	1.5707	1.58046	.01372	41.59	3.089
20	48.60	15.20	35.97	0.23	1.58974	1.5941	1.60488	.01514	39.24	3.290
30	41.18	12.88	45.74	0.20	1.62339	1.6284	1.64123	.01794	35.03	3.640
40	35.74	11.18	52.91	0.17	1.65375	1.6596	1.67397	.02022	32.62	3.942

Sodium Barium Glasses[114]—$100SiO_2 \cdot 20Na_2O \cdot xBaO$

	Weight percentage									
x	SiO_2	Na_2O	BaO	Al_2O_3 $+Fe_2O_3$	N_C	N_D	N_F	N_F-N_C	$\nu=\frac{N_D-1}{N_F-N_C}$	Sp.Gr.
5	74.7	15.4	9.5	0.4	(1.50119)	(1.5037)	(1.50961)	(.00842)	(59.8)	(2.557)
10	68.2	14.1	17.4	0.3	1.51757	1.5202	1.52642	.00895	58.8	2.708
15	62.7	13.0	24.0	0.3	1.53297	1.5357	1.54218	.00921	58.2	2.853
20	58.1	12.0	29.7	0.2	1.54546	1.5483	1.55503	.00957	57.3	2.987
30	50.6	10.4	48.8	0.2	1.56680	1.5698	1.57695	.01015	56.1	3.203
40	44.8	9.2	45.8	0.2	1.58635	1.5895	1.59602	.01067	55.3	3.407

Potassium Barium Glasses—$100SiO_2 \cdot 20K_2O \cdot xBaO$

	Weight percentage									
x	SiO_2	K_2O	BaO	Al_2O_3 $+Fe_2O_3$	N_C	N_D	N_F	$N_F—N_C$	$\nu=\frac{N_D-1}{N_F-N_C}$	Sp. Gr.
5	69.1	21.7	8.8	0.4	1.50549	1.5080	1.51673	.00844	60.2	2.565
10	63.5	20.0	16.2	0.3	1.51768	1.5203	1.52622	.00884	58.8	2.681
15	58.8	18.4	22.5	0.3	1.52897	1.5317	1.53819	.00922	57.7	2.798
20	54.6	17.2	27.9	0.3	1.54085	1.5437	1.55047	.00962	56.5	2.922
30	47.9	15.1	36.8	0.2	1.56219	1.5652	1.57239	.01020	55.4	3.143
40	42.7	13.4	43.7	0.2	1.58064	1.5838	1.59135	.01071	54.5	3.308

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[114] The results on the glass in this series with 5BaO were obtained by extrapolation.

Sodium Potassium Barium Glasses—$100SiO_2 \cdot 10Na_2O \cdot 10K_2O \cdot xBaO$

	Weight percentage										
x	SiO_2	Na_2O	K_2O	BaO	$Al_2O_3 + Fe_2O_3$	N_C	N_D	N_F	$N_F - N_C$	$\nu = \frac{N_D - 1}{N_F - N_C}$	Sp. Gr.
5	71.8	7.4	11.3	9.2	0.3	1.50333	1.5058	1.51165	.00832	60.8	2.562
10	65.8	6.8	10.3	16.8	0.3	1.51729	1.5199	1.52609	.00880	59.1	2.695
15	60.6	6.3	9.5	23.3	0.3	1.53146	1.5342	1.54067	.00921	58.0	2.821
20	56.2	5.8	8.9	28.8	0.3	1.54476	1.5476	1.55437	.00961	57.0	2.951
30	49.2	5.1	7.7	37.7	0.3	1.56640	1.5694	1.57657	.01017	56.0	3.175
40	43.7	4.5	6.9	44.7	0.2	1.58494	1.5881	1.59567	.01073	54.8	3.349

As silica seems to be the characteristic constituent of nearly all glasses Bannister[115] has devised a method of distinguishing between the various kinds of glass (by means of their physical characters) which is based on the way in which they differ from silica in their characters. The index of refraction of SiO_2 glass is taken as 1.46 and its density as 2.21. The chief types of commercial glasses may be identified by their position on a diagram which has the index of refraction as one coordinate and the ratio between $N - 1.46$ and $G - 2.21$ as the other coordinate. A modification of Bannister's diagram is shown in Fig. 310. The separation of the lead and calcium glasses is very distinct, but calcium glasses grade into borosilicate glasses and barium glasses overlap lead glasses considerably. These conditions are natural since there are so many variables in glass. Opal glasses are quite distinct. Natural glasses including obsidians and basalt glasses are also shown. The data include several glasses used as imitation gem stones.

Data for Figures 310 and 311

Borosilicate Glasses;

1. Imitation gem stone, Bannister's No. 14 in *Mineral. Mag.*, XXII, 1929, p. 136. No analysis, $N_D = 1.500$, G. = 2.36.
2. Borosilicate crown glass, Wright's No. 12 in *Jour. Am. Ceram. Soc.*, III, 1920, p. 783, and also in *Ord. Dept. U. S. Doc.* 2037, 1921. $SiO_2 = 72.0$, $B_2O_3 = 12.0$, $Na_2O = 11.0$, $Al_2O_3 = 5.0$, $N_D = 1.4997$; $\nu = 64.7$; G. = 2.37.
3. Borosilicate crown glass, Morey's No. 5 in *Intern. Crit. Tables*, II, 1927, p. 87. $SiO_2 = 59.5$, $B_2O_3 = 21.5$, $K_2O = 14.4$, $CaO = 0.3$, $Al_2O_3 = 1.9$, $ZnO = 2.3$, $As_2O_5 = 0.1$. $N_C = 1.49573$, $N_D = 1.4980$, $N_F = 1.50336$, $\nu = 65.3$, G. = 2.40.
4. Borosilicate crown glass, Wright's No. 15, *op. cit.* $SiO_2 = 70.6$, $B_2O_3 = 6.0$, $Al_2O_3 = 1.0$, $As_2O_3 = 0.3$, $Mn_2O_3 = 0.1$, $K_2O = 10.5$, $Na_2O = 11.5$. $N_C = 1.50446$, $N_D = 1.5069$, $N_F = 1.51259$, $\nu = 62.3$, G. = 2.48.

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[115] *Mineral. Mag.*, XXII, 1929, p. 136.

Calcium Glasses:

5. Hard crown glass, Morey's No. 27, *op. cit.* SiO_2 = 69.6, CaO = 11.5, K_2O = 1.84, Al_2O_3 = 0.3, As_2O_3 = 0.2. N_C = 1.51496, N_D = 1.5175, N_F = 1.52352, ν=60.5, G. = 2.49.
6. Imitation gem stone, Bannister No. 10, *op. cit.* No analysis. N_D = 1.538. G. = 2.57.

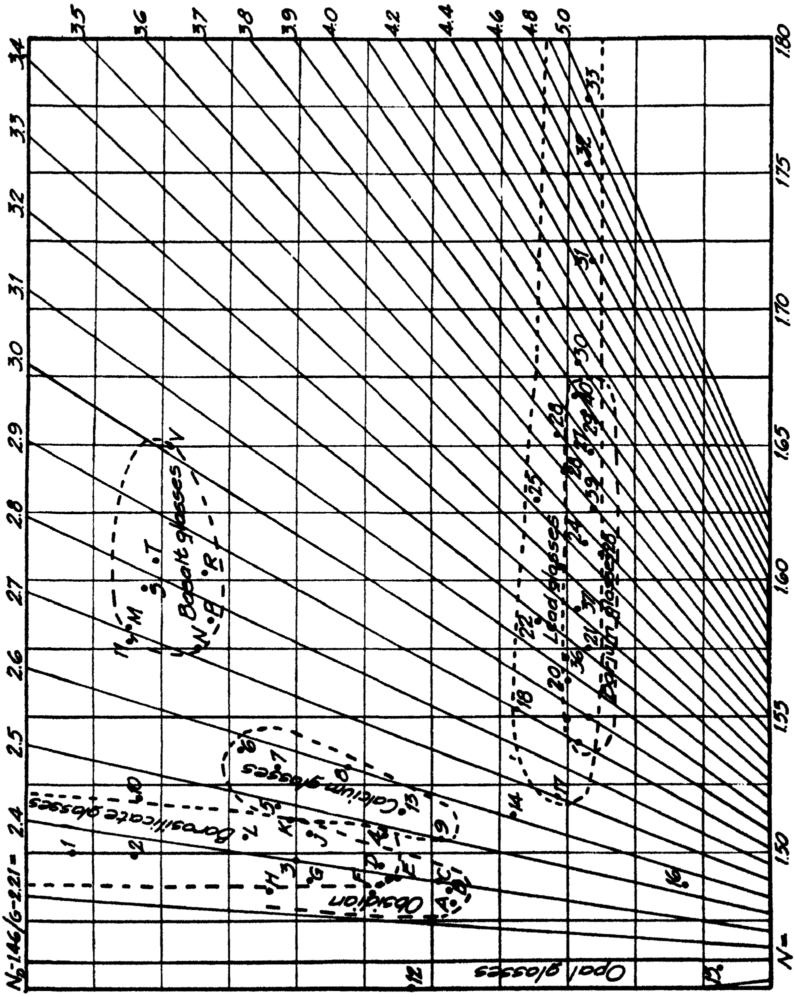

FIG 310.—Relations between refractive index and $N_D - 1.46/G. - 2.21$ in some artificial and natural glasses. Modified from Bannister: *Mineral. Mag.*, XXII, 1929, p. 136.

7. Imitation gem stone, Bannister, No. 8, *op. cit.* No analysis. N_D = 1.532, G. = 2.56.
8. Imitation gem stone, Bannister, No. 12, *op. cit.* No analysis. N_D= 1.532, G.= 2.60.
9. Ordinary crown glass, Wright's No. 1, *op. cit.* SiO_2 = 74.6, As_2O_3 = 0.3, Mn_2O_3=0.1, CaO = 5.0, K_2O = 11.0, Na_2O = 9.0. N_D = 1.5055, ν = 60.2, G. = 2.5.

Intermediate and Special Types:

10. Beryllium glass, Lai and Silverman's No. B3, in *Jour. Amer. Ceram. Soc.*, XL, 1928, p. 535: SiO_2 = 73.39, BeO = 7.64, Na_2O = 18.96. (= $Na_2O \cdot BeO \cdot 4SiO_2$.) N_D = 1.5193, G. = 2.45.
11. Imitation gem stone, Bannister's No. 18, *op. cit.* No analysis, but considered to be an iron calcium glass. N_D = 1.577. G. = 2.68.
12. Imitation gem stone, opal-white, Bannister's No. 24, *op. cit.* No analysis. N_D = 1.450, G. = 2.15.
13. Barium borosilicate crown glass, Morey's No. 18, *op. cit.* SiO_2 = 67.1, B_2O_3 = 7.2, Al_2O_3 = 0.3, As_2O_5 = 0.1, CaO = 2.0, BaO = 7.2, K_2O = 16.2. N_C = 1.51358, N_D = 1.5160, N_F = 1.52167, ν = 63.8, G. = 2.54.
14. Zinc crown glass, Morey's No. 16, *op. cit.* SiO_2 = 69.7, Al_2O_3 = 0.3, As_2O_5 = 0.4, CaO = 0.4, ZnO = 16.5, K_2O = 1.7, Na_2O = 11.0. N_C = 1.51225, N_D=1.5149, N_F = 1.52115, ν = 57.9. G. = 2.62.
15. Imitation gem stone, opal white, Bannister's No. 26, *op. cit.* No analysis. N_D = 1.457, G. = 2.17.
16. Imitation gem stone, dark brown, Bannister's No. 22, *op. cit.* No analysis, but considered to be colored by iron and titanium. N_D = 1.488, G. = 2.52.

Lead Glasses:

17. Flint glass, Wright's No. 47, *op. cit.* SiO_2 = 68.7, Mn_2O_3 = 0.1, As_2O_3 = 0.2, PbO = 13.3, ZnO = 2.0, Na_2O = 15.7. N_C = 1.51721, N_D = 1.5202, N_F= 1.52747, ν = 57.6, G. = 2.7.
18. Flint glass, Wright's No. 53, *op. cit.* SiO_2 = 59.3, As_2O_3 = 0.26, PbO = 27.5, K_2O = 8.0, Na_2O = 5.0. N_C = 1.54904, N_D = 1.5537, N_F = 1.56097, ν=45.0, G. = 2.9.
19. Flint glass, Morey's No. 48, *op. cit.* SiO_2 = 60.6, Al_2O_3 = 0.3, As_2O_5 = 0.1, CaO = 0.3, BaO = 2.5, PbO = 22.5, K_2O = 13.9. N_C = 1.54562, N_D=1.5491, N_F = 1.55768, ν = 45.5, G. = 2.95.
20. Flint glass, Morey's No. 55, *op. cit.* SiO_2 = 55.9, Al_2O_3 = 0.2, As_2O_5 = 0.1, CaO = 0.3, PbO = 32.0, K_2O = 11.1. N_C = 1.55045, N_D = 1.5632, N_F=1.57257, ν = 42.9, G. = 3.07.
21. Flint glass, Wright's No. 56, *op. cit.* SiO_2 = 53.7, Mn_2O_3 = 0.1, As_2O_3 = 0.3, PbO = 36.6, Na_2O = 1.0, K_2O = 8.3. N_C = 1.57122, N_D = 1.5752, N_F = 1.58507, ν = 41.0, G. = 3.22.
22. Imitation gem stone, red. Bannister's No. 7, *op. cit.* No analysis. N_D = 1.585. G. = 3.18.
23. Imitation gem stone, green. Bannister's No. 6, *op. cit.* No analysis. N_D = 1.606, G. = 3.42.
24. Flint glass, Morey's No. 92, *op. cit.* SiO_2 = 48.0, Al_2O_3 = 0.2, As_2O_5 = 0.1, PbO = 45.1, CaO = 0.3, Na_2O = 5.2, K_2O = 1.2, N_C = 1.60867, N_D = 1.6134, N_F = 1.62529, ν = 36.9, G. = 3.55.
25. Imitation gem stone, yellow. Bannister's No. 5, *op. cit.* No analysis, N_D = 1.630, G. = 3.53.
26. Imitation gem stone, yellow. Bannister's No. 4, *op. cit.* No analysis, N_D = 1.640, G. = 3.70.
27. Flint glass, Morey's No. 101, *op. cit.* SiO_2 = 40.6, Al_2O_3 = 0.2, As_2O_5 = 0.1, CaO = 0.2, PbO = 51.5, K_2O = 7.5, N_C = 1.64149, N_D = 1.6469, N_F = 1.66066, ν = 33.7, G. = 3.87.
28. Imitation gem stone, purple. Bannister's No. 3, *op. cit.* No analysis. N_D = 1.654, G. = 3.79.

29. Imitation gem stone, yellow. Bannister's No. 2, *op. cit.* No analysis. $N_D \doteq 1.662$, G. = 3.97.

30. Flint glass. Wright's No. 78, *op. cit.* $SiO_2 = 38.0$, $As_2O_3 = 0.2$, $PbO = 56.8$, $K_2O = 5.0$. $N_C = 1.67413$, $N_D = 1.6801$, $N_F = 1.69517$, $\nu = 31.7$, G. = 4.1.

31. Flint glass. Wright's No. 80, *op. cit.* $SiO_2 = 33.7$, $As_2O_3 = 0.3$, $PbO = 62.0$, $K_2O = 4.0$, $N_C = 1.71055$, $N_D = 1.7174$, $N_F = 1.73489$, $\nu = 29.5$, G. = 4.49.

32. Flint glass, Wright's No. 82, *op. cit.* $SiO_2 = 28.4$, $As_2O_3 = 0.1$, $PbO = 69.0$, $K_2O = 2.5$, $N_C = 1.74941$, $N_D = 1.7541$, $N_F = 1.77384$, $\nu = 27.5$, G. = 4.78.

33. Flint glass, Wright's No. 83, *op. cit.* $SiO_2 = 27.3$, $As_2O_3 = 0.1$, $PbO = 71.0$, $K_2O = 1.5$, $N_C = 1.76999$, $N_D = 1.7782$, $N_F = 1.79940$, $\nu = 26.5$, G. = 4.09.

33*a*. Flint glass, Wright's No. 84, *op. cit.* $SiO_2 = 22.0$, $PbO = 78.0$, $N_C = 1.87938$, $N_D = 1.8904$, $N_F = 1.91935$, $\nu = 22.3$, G. = 5.83.

33*b*. Flint glass, Wright's No. 87, *op. cit.* $SiO_2 = 18.0$, $PbO = 82.0$, $N_C = 1.94925$, $N_D = 1.0626$, $N = 1.99807$, $\nu = 19.7$, G. = 6.33.

Barium Glasses:

34. Barium crown glass, Morey's No. 43, *op. cit.* $SiO_2 = 57.1$, $B_2O_3 = 1.8$, $Al_2O_3 = 0.2$, $As_2O_5 = 0.1$, $CaO = 0.3$, $BaO = 26.9$, $Na_2O = 13.7$, $N_C = 1.53802$, $N_D = 1.5409$, $N_F = 1.54712$, $\nu = 59.4$, G. = 2.90.

35. Barium flint glass. Wright's No. 89, *op. cit.* $SiO_2 = 56.2$, $As_2O_3 = 0.3$, $PbO = 7.0$, $ZnO = 9.0$, $BaO = 15.0$, $K_2O = 11.0$, $Na_2O = 1.5$, $N_C = 1.54694$, $N_D = 1.5500$, $N_F = 1.55736$, $\nu = 53.3$, G. = 3.0.

36. Barium flint glass. Wright's No. 95, *op. cit.* $SiO_2 = 51.2$, $As_2O_3 = 0.3$, $PbO = 4.0$, $ZnO = 14.0$, $BaO = 20.0$, $K_2O = 5.0$, $Na_2O = 5.5$, $N_C = 1.56607$, $N_D = 1.5692$, $N_F = 1.57679$, $\nu = 52.9$, G. = 3.12.

37. Barium crown glass. Wright's No. 40, *op. cit.* $SiO_2 = 37.5$, $B_2O_3 = 15.0$, $Al_2O_3 = 5.0$, $As_2O_3 = 1.5$, $BaO = 41.0$, $N_C = 1.58703$, $N_D = 1.5899$, $N_F = 1.59673$, $\nu = 60.8$, G. = 3.32.

38. Barium crown glass. Wright's No. 45, *op. cit.* $SiO_2 = 31.0$, $B_2O_3 = 12.0$, $Al_2O_3 = 8.0$, $As_2O_3 = 1.0$, $BaO = 48.0$, $N_C = 1.60673$, $N_D = 1.6098$, $N_F = 1.61710$, $\nu = 58.8$, G. = 3.54.

39. Barium flint glass. Wright's No. 102, *op. cit.* $SiO_2 = 42.8$, $As_2O_3 = 0.5$, $PbO = 32.6$, $ZnO = 5.1$, $BaO = 10.8$, $K_2O = 7.5$, $Na_2O = 0.7$. $N_C = 1.62233$, $N_D = 1.6269$, $N_F = 1.63832$, $\nu = 39.1$, G. = 3.70.

40. Barium flint glass. Morey's No. 104, *op. cit.* $SiO_2 = 36.6$, $Al_2O_3 = 0.2$, $Sb_2O_3 = 0.6$, $As_2O_5 = 0.2$, $CaO = 0.2$, $BaO = 13.6$, $ZnO = 4.7$, $PbO = 39.2$, $N_C = 1.66207$, $N_D = 1.6683$, $N_F = 1.68173$, $\nu = 35.6$, G. = 3.98.

Thallium Glasses:

41. Thallium glass, Bannister's No. 3, *op. cit.* p. 152, $SiO_2 = 36.99$, $PbO = 18.06$, $K_2O = 37.49$, $Tl_2O = 7.46$. $N_C = 1.581$, $N_D = 1.586$, $N_F = 1.599$, $\nu = 32.5$, G. = 3.12.

42. Thallium glass, Bannister's No. 2, *op. cit.*, p. 152. $SiO_2 = 38.45$, $PbO = 18.81$, $K_2O = 12.63$, $Tl_2O = 29.38$, $N_C = 1.650$, $N_D = 1.657$, $N_F = 1.673$, $\nu = 28.6$, G. = 3.75.

43. Thallium glass, Bannister's No. 1, *op. cit.*, p. 152. $SiO_2 = 27.17$, $PbO = 23.98$, $K_2O = 12.07$, $Tl_2O = 36.36$. $N_C = 1.736$, $N_D = 1.744$, $N_F = 1.766$, $\nu = 24.8$, G. = 4.42.

44. Thallium glass, Bannister's No. 4, *op. cit.*, p. 152. $SiO_2 = 20.83$, $PbO = 24.82$, $K_2O = 0.00$, $Tl_2O = 55.01$, $N_C = 1.9276$, $N_D = 1.9431$, $N_F = 1.9808$, $\nu = 17.7$, G. = 6.03.

Natural Rock Glasses:

A. Rhyolite obsidian, Yellowstone Park, C. E. Tilley, *Mineral. Mag.*, XIX, 1922, p. 275, N_D = 1.482, G. = 2.353.

B. Rhyolite obsidian, Clifton, Ariz., B. Jezek; *Zeit. Kryst.*, LIII, 1913, p. 82, N_C = 1.4850, N_D = 1.4871, N_F = 1.4956, ν = 46.0, G. = 2.355. N_C and N_F by graphic solution from N for Li, Na and Tl.

C. Rhyolite obsidian, Easter Island, Pacific, C. E. Tilley, *op. cit.*, N_D = 1.490, G. = 2.400.

D. Rhyolite obsidian, Greenland, B. Jezek, *op. cit.* N_C = 1.4939, N_D = 1.4956, N_F = 1.5002, ν = 67.0, G. = 2.413.

E. Rhyolite obsidian, Real del Monte, Mexico, B. Jezek, *op. cit.* N_C = 1.4889, N_D = 1.4912, N_F = 1.4970, ν = 60.6, G. = 2.413.

F. Rhyolite obsidian, Papayan, Columbia, B. Jezek, *op. cit.* N_C = 1.4830, N_D = 1.4852, N_F = 1.4925, ν = 51.1,. G. = 2.352.

G. Rhyolite obsidian, Lipari Island, C. E. Tilley, *op. cit.* N_D = 1.490, G. = 2.363.

H. Rhyolite obsidian, Guamani, Ecuador, B. Jezek, *op. cit.* N_C = 1.4840, N_D = 1.4863, N_F = 1.4941, ν = 48.1, G. = 2.336.

J. Trachyte obsidian, Pantelleria, C. E. Tilley, *op. cit.* N_D = 1.508, G. = 2.454.

K. Trachyte obsidian, Ascension, C. E. Tilley, *op. cit.* N_D = 1.506, G. = 2.435.

L. Trachyte obsidian, Teneriffe, C. E. Tilley, *op. cit.* N_D = 1.512, G. = 2.467.

M. Basalt glass, Gallanach, Muck Island, C. E. Tilley, *op. cit.* N_D = 1.583, G.= 2.704.

N. Basalt glass, Portree, Skye, C. E. Tilley, *op. cit.* N_D = 1.576, G. = 2.716.

P. Basalt glass, Vesuvius (1805), C. E. Tilley, *op. cit.* N_D = 1.586, G. = 2.769.

R. Basalt glass, Kau desert, Kilauea, C. E. Tilley, *op. cit.* N_D = 1.603, G. = 2.841.

S. Basalt glass, Caisteal, Muck Isl., C. E. Tilley, *op. cit.* N_D = 1.598, G. = 2.773.

T. Basalt glass, Reunion Island, C. E. Tilley, *op. cit.* N_D = 1.608, G. = 2.825.

V. Basalt glass, Kildonan, Eigg Isl., C. E. Tilley, *op. cit.* N_D = 1.649, G. = 3.003.

Wright[116] has shown that glasses are well characterized by their refractive index and dispersion. They are equally well characterized by the refractive index and the more familiar reciprocal of the dispersion, which is called ν and equals $\frac{N_D - 1}{N_F - N_C}$. These values are the coordinates used in Fig. 311, which shows that the lead glasses fall along a remarkably smooth curve, the calcium glasses fall close together and the borosilicate glasses form another small group, while the barium glasses scatter over a large area; the thallium glasses, recently made by Bannister,[115] fall along a curve nearly parallel with that of the lead glasses. Natural acid volcanic glasses or obsidians vary in dispersion much more than in refractive index, which is low. Basalt glasses have a refractive index ranging from about 1.58 to about 1.67, but their dispersion is apparently unknown. It should be understood that there are all gradations between the various artificial types of glass, and also between obsidians and basalt glasses. Wright and Peddle have both worked out diagrams and tables from which the batch composition necessary to give certain physical properties of glass may be derived.

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[116] F. E. Wright: Optical Glass: *U. S. Ord. Dept. Doc.* 2037, 1921, and *Jour. Am. Ceram. Soc.*, III, 1920, p. 783.

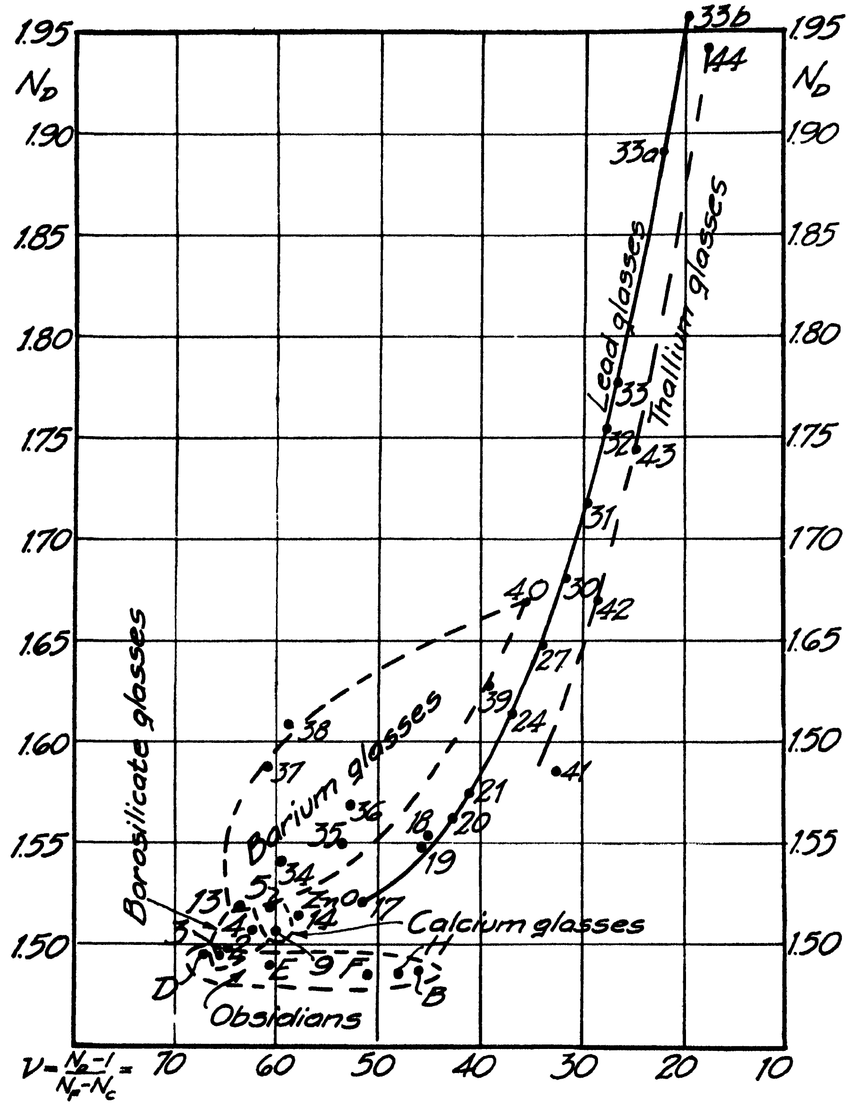

FIG. 311.—Relations between refractive index and dispersion as measured by $\nu = \frac{N_D - 1}{N_F - N_C}$ in some artificial glasses and obsidians.

It is reported that glass for bottles will soon be manufactured in Canada from feldspar;[117] such glass is said to be tougher than ordinary bottle glass; high purity of the crude feldspar is said to be unnecessary. If pure plagioclase feldspar were used the glass would have the following optical properties:[118]

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[117] H. S. Spence: *Min. Metal.* XI, 1930, p. 103.

Per Cent Albite	Per Cent Anorthite	N_C	N_D	N_F	ν	G.
100.0	0.0	1.4870	1.4890	1.4957	56.2	2.382
65.37	34.63	1.5141	1.5166	1.5231	57.4	2.483
48.55	57.45	1.5282	1.5307	1.5375	58.3	2.533
32.05	67.95	1.5427	1.5452	1.5520	58.6	2.597
15.87	84.13	1.5571	1.5600	1.5665	59.6	2.648
0.0	100.0	1.5725	1.5755	1.5828	60.6	2.700

[118] E. S. Larsen: *Am. Jour. Sci.*, XXVIII, 1909, p. 263; N_C, N_F (and ν) by graphic solution from indices for lithium, sodium and thallium light given by Larsen.

PART III

DETERMINATIVE TABLES

Part III

DETERMINATIVE TABLES

DETERMINATIVE TABLES FOR THE IDENTIFICATION OF ARTIFICIAL INORGANIC SOLID SUBSTANCES BY MICROSCOPIC METHODS

Introductory Statement

The following tables include only those artificial inorganic solid substances included in the preceding descriptive text; indeed some of those described are not included in the tables. Those omitted include all glasses of indefinite composition and the zeolites (and a few others) which are included in the descriptive text, not because the artificial products have been measured optically, but as a basis of comparison with artificial products made from them.

In the tables artificial inorganic solid substances are first divided into two classes, namely, isotropic and anisotropic. The first table includes all isotropic artificial inorganic solid substances of definite composition, whose refractive indices have been measured, and they are arranged in the order of increasing index of refraction. Substances which vary in index of refraction are shown to vary by a line along the right margin of the index column from the minimum value to the maximum value; the second column shows the dispersion in ordinary type for $N_F - N_C$ or in smaller type for $N_{Tl} - N_{Li}$; the third column gives the chemical formula of the substance; the fourth column gives the number of distinct cleavage directions and the Miller symbols for the form to whose faces the cleavage directions are parallel; the next two columns give characters which may be useful in microscopic study and the last column gives the page in this book on which the substance is described.

The second table includes all anisotropic artificial inorganic solid substances whose optic properties have been measured; they are arranged in the order of increasing index of refraction (N_o or N_m). It should be noted that N_o is used for uniaxial crystals because every grain of whatever orientation will give this index at one position, or the other, of extinction; the index N_m is used for biaxial crystals because every grain of whatever orientation will give two indices of refraction, one of which must be equal to, or less than, N_m, while the other must be equal to, or greater than, N_m. Therefore, with a biaxial crystal, by measuring the indices of several grains or crystals at both positions of extinction a table can be prepared which will give the approximate value of N_m. For example, if the table reads as follows:

Grains Number	Index of Refraction	
	Larger Value	Smaller Value
1	1.654	1.618
2	1.632	1 620
3	1.666	1.625
4	1.626	1.612

The value of N_m cannot be less than 1.625 nor more than 1.626 and greater accuracy is not always necessary. Furthermore, any grain which is so oriented as to give the lowest interference color for the given crystal is nearly or quite normal to an optic axis and will therefore give two indices of refraction which are nearly or quite equal to each other and to N_m.

Positive and negative crystals can be picked out quickly by the fact that the index (N_o or N_m) is set at the left margin for optically positive crystals and indented two spaces to the right for optically negative substances; a few substances of unknown optic sign have the index at an intermediate position.

If a given substance varies in index of refraction for any reason the range of variation is shown by means of a vertical line at the right hand side of the first column.

The second column of Table II gives the dispersion of each substance (if known), in ordinary type for the value F − C and in smaller type for the value Tl − Li, for N_o or N_m.

The third and fourth columns of Table II give the maximum and minimum indices of refraction (or the birefringence, if these have not been measured); the fifth column gives the value of the true optic axial angle of the substance and the next column gives the chemical formula of each substance. The other columns of Table II give the physical characters which may be useful in microscopic study of crystals and the last column gives the page in this book on which the substance is described.

The double variation method is recommended for measuring indices of refraction. For the explanation of abbreviations used in the tables see the list of abbreviations on page xvi.

TABLE I—ISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES

N_D	$N_F - N_C$	$N_{Tl} - N_{Li}$	Substance	Cleavage	Specific Gravity	Crystal Habit, Color, etc.	Page
1.3258	.0039		NaF	3–100	2.80	Cubes, red. Also biref.	160
1.3391 ↑	?		K_2SiF_6	4–111	2.75	Cubic or octah. Also hex.	179
1.352	?		KF	3–100	2.49	Cubes.	161
1.3696	.0041		$(NH_4)_2SiF_6$	4–111	2.01	Octah. Also hex.	179
1.39± ↓	?		K_2SiF_6	4–111	?	Microchem. test for K.	179
1.3915	?		LiF	3–100	2.64	Cubes.	161
1.396	.005		RbF	3–100	3.74	Hygroscopic.	161
1.408	?		K_3ZrF_7	?	?	Octahedral.	180
1.410	?		KCN	?	1.52	Cubes or octah.	161
1.412 C	?		$SiCl_4$	?	1.48+		172
1.413 ↑		.011	$K_2Zn(CN)_4$	?	1.673	Octahedral.	• 173
1.421 ↓↑		.010	$K_2Cd(CN)_4$	?	1.824	Octahedral.	173
1.426	?		$(NH_4)_3HfF_7$	?	?		179
1.433	?		$(NH_4)_3ZrF_7$	?	?	Octahedral.	179
1.434	.0045		CaF_2	4–111	3.18	Cubic; octah. Tinted±.	165
1.438	?		SrF_2	?	4.24		166
1.4388	.0076		$NaAl(SO_4)_2 \cdot 12H_2O$	?	1.69	Octah. Na alum.	259
1.450	?		$Na_3PO_4 \cdot 10H_2O$	?	?	Octah. Dodecah.	269
1.452		.006	$Na_7FP_2O_8 \cdot 19H_2O$	?	2.22	Octahedral.	269
1.452	?		NaCN	?	?		161
1.453	?		KH	?	?	Fibrous	162
1.4564	.0060		$KAl(SO_4)_2 \cdot 12H_2O$	None	1.76	Octah. or cubic. K alum.	259
1.4566	.0077		$RbAl(SO_4)_2 \cdot 12H_2O$	None	1.89	Pyritoh. Rb alum.	260
1.458 ↓		.010	$K_2Hg(CN)_4$	?	2.44	Octahedral.	173
1.4586	.0077		$CsAl(SO_4)_2 \cdot 12H_2O$	None	1.97	Pyritoh. Cs alum.	260
1.4588	?		SiO_2 (glass)	None	2.19	Lechatelierite	194

1.459	?	B_2O_3 (glass)	None	?		188
1.4594	.0079	$NH_4Al(SO_4)_2 \cdot 12H_2O$	?	1.64	NH_4 alum.	259
1.4638	.0083	$RbIn(SO_4)_2 \cdot 12H_2O$	?	2.06		260
1.462–5 Li	?	$RbTi(SO_4)_2 \cdot 12H_2O$	?	?	Pyritoh. Red.	260
1.465	?	$NaK(CN)_2$	?	?		161
1.4650	.0079	$CsGa(SO_4)_2 \cdot 12H_2O$	?	2.11		260
1.4652	.0083	$CsIn(SO_4)_2 \cdot 12H_2O$	?	2.24	Cubes or octah.	260
1.4653	.0079	$KGa(SO_4)_2 \cdot 12H_2O$	?	1.90		260
1.4658	.0080	$RbGa(SO_4)_2 \cdot 12H_2O$	?	1.96		260
1.4664	.0088	$NH_4In(SO_4)_2 \cdot 12H_2O$	?	2.01	Unstable.	260
1.4684	.0083	$NH_4Ga(SO_4)_2 \cdot 12H_2O$	?	1.78		260
1.469	.007	$Na_7FAs_2O_8 \cdot 19H_2O$	?	?	Octahedral.	269
1.469	?	$RbV(SO_4)_2 \cdot 12H_2O$	None	1.915	Octah.? Violet.	260
1.470	?	NaH	?	?	Fibrous.	162
1.472	?	$NaAlSi_2O_6 \cdot H_2O$	None	2.25	Also weak biref.	315
1.4736	.004±	$CsTi(SO_4)_2 \cdot 12H_2O$	None	?	Octah.; pyritoh. Red.	260
1.475	?	BaF_2	?	4.83		166
1.475	?	$NH_4V(SO_4)_2 \cdot 12H_2O$	None	1.69	Octah.?	166
1.478	?	$CsV(SO_4)_2 \cdot 12H_2O$	?	2.03	Octah.?	260
1.478	.006	CsF (low)	?	4.52		162
1.480	?	SiO_2 (gel)	None	?	N after ignition.	194
1.4801	.0095	$KAl(SeO_4)_2 \cdot 12H_2O$	?	2.00	Also biref.	260
1.4810	.0088	$CsCr(SO_4)_2 \cdot 12H_2O$	?	2.04	Octah. Red	260
1.4814	.0088	$KCr(SO_4)_2 \cdot 12H_2O$	None	1.85	Cubes; octah. Red.	260
1.4815	.0091	$RbCr(SO_4)_2 \cdot 12H_2O$	?	1.97	Octah. Red.	260
1.4817	.0110	$KFe(SO_4)_2 \cdot 12H_2O$	?	1.83	Violet±.	260
1.4823	.0111	$RbFe(SO_4)_2 \cdot 12H_2O$	?	1.92	Violet±.	260
1.483 Li	?	$CsMn(SO_4)_2 \cdot 12H_2O$	None	?	Octah. Red.	260
1.4838	.0110	$CsFe(SO_4)_2 \cdot 12H_2O$	?	2.06	Violet±.	260
1.484	.006	CsF (low)	?	4.52		162

TABLE I.—ISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_D	$N_F - N_C$	$N_{Tl} - N_{Li}$	Substance	Cleavage	Specific Gravity	Crystal Habit, Color, etc.	Page
1.4842	.0091		$NH_4Cr(SO_4)_2 \cdot 12H_2O$	?	1.73	Octah. Red.	260
1.4848–54	.0114		$NH_4Fe(SO_4)_2 \cdot 12H_2O$	?	1.72	Violet±. Also biref.	260
1.486	?		SiO_2	?	2.27	Metacristobalite.	191
1.4891		.0052	$NaAlSi_3O_8$ (glass)	None	2.38		311
1.4904	.0112		KCl	3–100	1.99	Cubes.	160
1.4936	.0113		RbCl	3–100	2.81	Cubes.	161
1.495	?		$LiAlSi_4O_{10}$ (glass)	None	2.29		310
1.4975	.0102		$TlAl(SO_4)_2 \cdot 12H_2O$	?	2.33	Also strong biref.	260
1.500	?		$2NaCl \cdot 7KCl$	3–100	?	Cubes.	160
1.501±		.006	$RbRh(SO_4)_2 \cdot 12H_2O$	None	?	Yellow.	260
1.501±	?		$KAlSi_2O_6$	None	2.47	Leucite. Also biref.	309
1.503	?		$2NaCl \cdot 5KCl$	3–100	3–100	Cubes.	160
1.5067	.0104		$TlGa(SO_4)_2 \cdot 12H_2O$	?	2.48		260
1.5070		.0072	$RbFe(SeO_4)_2 \cdot 12H_2O$	?	2.13	Octah. Violet±?	260
1.5077		.0049	$CsRh(SO_4)_2 \cdot 12H_2O$	?	?	Octah. Yellow.	260
1.508	?		$KAlSiO_4$ (glass)	None	?		308
1.5085	?		$2NaCl \cdot 3KCl$	3–100	?	Cubes.	160
1.510	?		$NaAlSiO_4$ (glass)	None	?		307
1.5103		.0077	$NH_4Rh(SO_4)_2 \cdot 12H_2O$	?	?	Octah. Yellow.	260
1.5116		.0074	$CsFe(SeO_4)_2 \cdot 12H_2O$	?	3.62	Octah. Violet±.	260
1.5139	?		$Mg(BrO_3)_2 \cdot 6H_2O$	?	2.29	Octah.	205
1.514	?		$TlV(SO_4)_2 \cdot 12H_2O$	None	2.34	Octah.? Violet.	260
1.514	?		$NaCl \cdot KCl$	3–100	?	Cubes.	160
1.5147	?		$Na_2B_4O_7$ (glass)	None	?		213
1.5151	.0089		$NaClO_3$	None	2.49	Cubic, tetrah.; twins.	204
1.518	?		$4NaCl \cdot 3KCl$	3–100	?	Cubes.	160

1.519	?		LiAlSi$_2$O$_6$ (glass)	None	2.36		307
1.519	?		3NaCl·2KCl	3–100	?	Cubes.	160
1.5228	0116		TlCr(SO$_4$)$_2$·12H$_2$O	?	2.39	Octah. Red.	260
1.523	?		2NaCl·KCl	3–100	?	Cubes.	160
1.5230		.0113	Na$_7$FV$_2$O$_8$·19H$_2$O	?	?	Octah.	269
1.523	?		K$_2$Be$_3$Si$_4$O$_{12}$	?	2.53	Also weak biref.	306
1.5237	.0134		TlFe(SO$_4$)$_2$·12H$_2$O	?	2.38	Octah. Violet±.	260
1.528	?		3NaCl·KCl	3–100	?	Cubes.	160
1.5305		.0122	Na$_3$VO$_4$·10H$_2$O	?	?	Dodecah. Also hex.	269
1.533	?		5NaCl·KCl	3–100	?		160
1.534	.012		CsCl	?	3.56	Cubes.	162
1.536	?		7NaCl·KCl	3–100	?		160
1.540	?		K$_2$Al$_2$SiO$_6$	?	?	Octah.	308
1.541	?		LiAlSiO$_4$	None	?		308
1.5443	.0127		NaCl	3–100	2.17	Cubes.	160
1.5452	?		Zn(BrO$_3$)$_2$·6H$_2$O	?	2.51	Octah.	205
1.548	?		Li$_2$SiO$_3$ (glass)	None	2.35		281
1.548		.003±	TlRh(SO$_4$)$_2$·12H$_2$O	?	?	Octah. Yellow.	260
1.5528	.0183		RbBr	3–100	3.35	Cubes.	161
1.5594	.0169		KBr	3–100	2.75	Cubes.	161
1.56	?		CdF$_2$	?	?		165
1.564	?		Cr$_2$(SO$_4$)$_3$·18H$_2$O	None	?	Powder.	235
1.5667	?		SrN$_2$O$_6$	?	2.99	Tetrah.	208
1.571	?		Na$_4$CaSi$_3$O$_9$	?	2.78	Octah., pyritoh.	305
1.571	.0160		BaN$_2$O$_6$	?	3.25	Tetrah. Also biref.	207
1.572	?		K$_4$CaSi$_3$O$_9$	?	?	Octah.	306
1.5755		.0067	CaAl$_2$Si$_2$O$_8$ (glass)	None	2.70		319
1.578	.008		CsF	3–100	5.34	Cubes.	162
1.579	?		SiBr$_4$	?	2.81		172
1.5801	?		MgSiO$_3$ (glass)	None	2.76		294

TABLE I.—ISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_D	$N_F - N_C$ $N_{Tl} - N_{Li}$	Substance	Cleavage	Specific Gravity	Crystal Habit, Color, etc.	Page
1.571	.0160	BaN_2O_6	?	3.25	Tetrah. Also biref.	207
1.582	.017	CsBr	3–100	3.75	Cubes.	162
1.5878	?	SrN_2O_6	?	2.99	Tetrah.	208
1.589	?	$SrN_2O_4 \cdot H_2O$	Poor	2.99	Cubes.	211
1.5943	?	$NaBrO_3$	?	3.3	Tetrah. Also biref.	204
1.60	?	Na_2CaSiO_4	?	2.79		305
1.604	?	$Ca_3Al_2O_6 \cdot 6H_2O$	?	2.52	Trapezoh., cubes.	197
1.606	?	$BaSi_2O_5$ (glass)	None	?		287
1.607	?	GeO (glass)	None	3.64		194
1.608–13	?	$Ca_5Al_6O_{14}$	None	?		196
1.617	.0134	$NaBrO_3$	?	3.3	Tetrah. Also biref.	205
1.6269	?	$GeBr_4$	?	3.13	Octah. G. as a liquid.	172
1.6280	?	$CaSiO_3$ (glass)	None	2.90		297
1.638	?	$Ca_2Al_2SiO_7$ (glass)	None	2.9±		317
1.639	?	NH_4Cl	Poor	1.53	Tetrah.	164
1.641	?	$Ca_2MgSi_2O_7$ (glass)	None	3.2±		284
1.6412	.0200	NaBr	3–100	3.20	Cubes.	161
1.6418	.0146	CsCl	?	3.97	Cubes.	162
1.6426	.0149	NH_4Cl	Poor	1.53	Tetrah.	164
1.6439	?	$(NH_4)_2FeCl_4$	?	?		173
1.644	?	Li_2O	Dist.	2.01	Oxidizes. Also biref.	184
1.6474	.0275	RbI	3–100	3.56	Cubes.	161
1.6499	?	$SrCl_2$	?	3.08		166
1.65	?	Al_2O_3 (gel)	None	4.0±	N after ignition	188
1.650	?	$ZnSiO_3$ (glass)	None	3.86		288
1.650–4	?	$FeSiO_3 \cdot nH_2O$	None	2.8±	Amorphous. Green	304

1.6574	.020	K_2SnCl_6	4-111	2.69	Octah.	179
1.661	.018	CsI	3-100	3.82	Cubes.	163
1.662	?	$Ca_5Al_6O_{14}$ (glass)	None	?		196
1.662	?	LiCl	3-100	2.07	Cubes.	161
1.6670	.0287	KI	3-100	3.13	Cubes.	161
1.67-8	?	$MgAl_2O_4$ (glass)	None	?		195
1.69	?	Al_2O_3 (gel)	None	4.0±	N after ignition.	188
1.696	?	Al_2O_3	?	3.47	High temp. phase.	188
1.6984	.0202	CsBr	?	4.45	Cubes.	162
1.700	?	$MnSiO_3$ (glass)	None	3.48		299
1.7031	.0331	NH_4I	3-100	2.50	Cubes.	161
1.710-5	?	$Ca_3Al_2O_6$	Poor	?		195
1.7108	.0088	NH_4Br	3-100	2.44	Tetrah.	164
1.718	.012±	$MgAl_2O_4$	Poor	3.6	Octah. Spinel. Tinted±.	195
1.734	.014	MgO	3-100	3.58	Cubes. Octah.	185
1.735	?	$Ca_3Al_2Si_4O_{12}$	Poor	3.4	Dodecah. Garnet.	316
1.7366	.014	MgO	3-100	3.58	Cubes. Octah.	185
1.755	.015±	As_2O_3	4-111	3.71	Arsenolite.	188
1.76	.012±	$MgAl_2O_4(+9\%MgFe_2O_4)$	Poor	3.7±	Octah. Red.	195
1.7745	?	NaI	3-100	3.65	Cubes.	161
1.78+	?	$CoAl_2O_4$	?	?	"Cobalt blue."	195
1.7815	.0335	PbN_2O_6	None	4.54	Tetrah. Also mono.	208
1.784	?	LiBr	3-100	3.46	Cubes.	161
1.7876	.0329	CsI	?	4.54		163
1.791	.03±	$CsHgCl_3$	None	?	Octah. Also biref.	174
1.8	?	$(NH_4)_2PtCl_6$	4-111	3.0	Octah.	179
1.805	?	$ZnAl_2O_4$	?	4.58	Octah.	195
1.825±	?	K_2PtCl_6	4-111	3.6	Octah., cubes.	179
1.837	.013±	CaO	3-100	3.32	Cubes. Hydrates.	186
1.870	.024±	SrO	3-100	4.75	Cubes. Hydrates.	186
1.955	?	LiI	3-100	4.06	Cubes.	161

TABLE I.—ISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_D	$N_F - N_C$	$N_{Tl} - N_{Li}$	Substance	Cleavage	Specific Gravity	Crystal Habit, Color, etc.	Page
1.973		.041	CuCl	6–110	4.14	Tetrah. Nantokite.	163
1.98		.044	BaO	3–100	6.09	Cubes. Hydrates.	186
1.998		.040	S (glass)	None	2.0±	Yellow. Sulphur.	153
2.00±	?		$Fe_2O_3 \cdot nH_2O$	?	3.8±	Yellow to red.	190
2.001	?		Hg_3OCl_4	?	6.39	Dodecah., octah.	182
2.071	?		AgCl	None	5.5	Octah. Chlorargyrite.	161
2.106		.098	SnI_4	?	4.70	Red.	172
2.107	.054±		SrS	3–100	3.91	Cubes.	156
2.116		.072	CuBr	6–110	5.17	Tetrah.	164
2.117	.065		P	?	1.84	Dodecah. Burns.	153
2.137	.055±		CaS	3–100	2.71	Cubes.	156
2.15±	?		$Fe_2O_3 \cdot nH_2O$	?	3.8±	Yellow to red.	190
2.155	.063±		BaS	3–100	4.38	Cubes.	156
2.18	?		ZnS (glass?)	None	?	Brown±. Also biref.	158
2.22		.062	SrSe	3–100	4.54	Cubes.	156
2.247	.110±		TlCl	?	?	Tetrah.	163
2.25	?		ZnS (glass?)	None	?	Brown±. Also biref.	158
2.252	.06±		AgBr	None	6.2	Bromyrite.	161

2.268		.031	MgS	3–100	2.84	Cubes.	156
2.271		.07±	BaSe	?	4.94	Cubes.	156
2.274		.06±	CaSe	?	3.81	Cubes.	156
2.31 Li	?		$ZnFe_2O_4$	?	5.3	Octah.	195
2.345		.075±	CuI	6–110	5.69	Tetrah.	164
2.36	?		AgI+AgBr	None	?	Octah.	162
2.368		.058	ZnS	6–110	4.09	Dodecah. Sphalerite.	157
2.37	.02±		NiO	?	6.4	Octah. Green.	186
2.39 Li	?		$MgFe_2O_4$	None	4.6	Octah.	195
2.39 Li	?		$CdFe_2O_4$	?	5.8		195
2.408		.100	SrTe	?	5.22		156
2.418		.09±	TlBr	?	?		163
2.42+	?		MgSe	?	4.27		156
2.44		.15	BaTe	?	7.59		157
2.47		.06±	ZnS(+FeS)	6–110	?	Dodecah. Sphalerite.	157
2.49 Li	?		CdO	?	8.15	Red-brown.	186
2.5+	?		CaTe	?	4.87		156
2.705	.405		Cu_2O	Poor	5.98	Octah., cubes. Red.	185
2.78±		.18±	TlI	?	?		163
2.92	?		Se (glass)	None	?		153
3.56	?		ZnTe	?	5.54	Red.	158

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES

N_o or N_m				N_g or N_g-N_p	N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F−C	Tl−Li								
1.3090		.0062		1.3104	1.3090	0°	H_2O	H	1−0001	Ice	185
	1.3125	.0024		1.3125	1.3089	Sm.	Na_2SiF_6	O	?	X ∥ Ps. Hex. prism	180
	1.3245		.003±	1.3239	1.3245	Mod.	KBF_4	O	?	X⊥001 tablets	177
	1.3258	.0039		Very weak		0°	NaF	Q	3−100, 001	Yellow to red	160
1.3439		.0046		1.3602	1.3439	0°	$MgSiF_6\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong.	180
1.352		?		1.363	1.345	Lg.	$KF\cdot 2H_2O$	M?	?		165
1.36		?		?	?	?	$CsBF_4$	O	?		177
1.3570		.0053		1.3742	1.3570	0°	$MnSiF_6\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong. Pink	180
1.3638			.0037	1.3848	1.3638	0°	$FeSiF_6\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong.	180
1.3817 C		?		1.3872	1.3817	0°	$CoSiF_6\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong. Red	181
1.3824		.0052		1.3956	1.3824	0°	$ZnSiF_6\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong.	181
1.384		.006		1.399	1.384	0°	$CoF_2\cdot 5HF\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong. Red	168
1.389		?		1.627	1.389	0°	NaCNO	R	3−10$\bar{1}$1	Z⊥plates	183
	1.390	?		1.394	1.385	Sm.	NH_4HF_2	O	?	X ∥ elong.	165
1.3910		.0074		1.4060	1.3910	0°	$NiSiF_6\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong. Green	181
1.392		.005		1.408	1.392	0°	$NiF_2\cdot 5HF\cdot 6H_2O$	R	3−11$\bar{2}$0	Z ∥ elong. Green	168
	1.396	?		1.398	1.394	76°	$Na_2SO_4\cdot 10H_2O$	M	1−100	Y ∥ elong. Z∧c=30°	220
	1.4±	?		1.52?	1.38?	40°±	$CoN_2O_6\cdot 6H_2O$	M	1−001	Red	211
	1.406	?		1.406	1.391	0°	$(NH_4)_2SiF_6$	H	1−0001	0001 tablets	179
	1.4092	.0064		1.4092	1.4080	0°	$CuSiF_6\cdot 6H_2O$	R	Poor	Blue	181
	1.417	?		1.417	1.393	0°	$CaCl_2\cdot 6H_2O$	R	4−0001, 10$\bar{1}$0	Deliquescent	168
	1.425	?		1.440	1.405	71°	$Na_2CO_3\cdot 10H_2O$	M	1−001	Y=*b*; Z∧*c*=41°	200
1.4309			.0053	1.4493	1.4193	78°	$NaH_2PO_3\cdot 2\frac{1}{2}H_2O$	M	?	Y=*b*; Z∧*c*=55°	278
1.436		?		1.439	1.436	0°	$Na_2SO_4\cdot NaF$	H	0001	0001 tablets	267
	1.4361		.0059	1.4373	1.4321	57°	$Na_2HPO_4\cdot 12H_2O$	M	?	Y=*b*; X∧elong.=31°	271
1.437 Li		?		?	?	37°	NH_4LiSO_4	O	1−100	X⊥100 plates	219

1.440		?	1.444	1.395	32°	$CuF_2 \cdot 5HF \cdot 6H_2O$	M	3	Blue	171
1.442		?	1.469	1.439	36°	$NH_4NaHPO_4 \cdot 4H_2O$	M	None	X∧elong. = 10°	270
1.4424		.0054	1.4526	1.4412	39°	$Na_2HPO_4 \cdot 7H_2O$	M	?	X∧⊥001 plates = 11°	271
1.4434		?	Weak		44°	$Na_2HPO_3 \cdot 5H_2O$	O	?	Y ∥ elong.	278
1.4458		?	1.4524	1.4458	0°	$Na_3PO_4 \cdot 12H_2O$	R	?	Z ∥ elong.	269
1.447		.180	1.561	1.321	14°	$Na_2CrO_4 \cdot 4H_2O$	M	None	X∧elong. = 10°	221
1.4496		.0065	1.4513	1.4453	65°	$Na_2HAsO_4 \cdot 12H_2O$	M	?	X∧elong. = 1°	271
1.45±		?	1.485	1.44	32°	$NH_4B_5O_8 \cdot 4H_2O$	O	1–010	Y⊥cleav.	213
1.452		?	1.458	1.430	52°	$KAl(SO_4)_2 \cdot 12H_2O$	M	?	Y∧elong. = 13°	259
1.4525		.0055	1.4604	1.4499	60°	$Na_4P_2O_7 \cdot 10H_2O$	M	?	Z⊥101±	279
1.454		?	1.467	1.447	Mod.	$Na_2SiO_3 \cdot 5H_2O$	T	?		284
1.4550		.0063	1.5153	1.4550	0°	$K_2S_2O_6$	H	?	Z ∥ elong.	262
1.455+		?	1.460	1.451	90°±	$Na_2SiO_3 \cdot 9H_2O$	O	None	Y = *b*, Z = *c*	284
1.4554	↑↑	.0077	1.4608	1.4328	51°	$MgSO_4 \cdot 7H_2O$	O	1–010	X⊥010 cleav.	226
1.456		?	1.456	1.429	0°	$KAl(SO_4)_2 \cdot 12H_2O$	?	?	Kalinite	259
1.4565		.0069	1.5068	1.4573	0°	$Rb_2S_2O_6$	R	?	Z ∥ elong.	262
1.4589		.0071	1.4669	1.4589	0°	$Na_3AsO_4 \cdot 12H_2O$	R	?	Z ∥ elong.	269
1.46±		?	1.47±	1.43±	Sm.	$NaHSO_4 \cdot H_2O$	M	?	Prisms or platy	221
1.461		?	1.474	1.461	0°	$Na_2B_4O_7 \cdot 5H_2O$	R	None	Ps.-octah. G. = 1.88	212
1.461		?	1.463	1.449	56°	$NaAl(SO_4)_2 \cdot 12H_2O$	M	2–010, 100	X⊥010 cleav.	259
1.4617		?	1.473	1.461	Sm.	$NaClO_4$	O	?	G. = 2.50	206
1.4629		.0055	1.4815	1.4401	83°	$NaH_2PO_4 \cdot 2H_2O$	O	?	Pyramidal, etc. G. = 1.92	270
1.4629		.0071	1.4755	1.4607	48°	$K_2Mg(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 28°	240
1.463		?	1.465	1.438	29°	$MgSO_4 \cdot 6H_2O$	M	2–110	X∧cleav. = 25°	231
1.463		.0090+	1.465+	1.457+	63°	$Na_2SiO_3 \cdot 8H_2O$	M	?	X∧*c* = 12°; Y = *b*	284
1.464		?	1.464	1.458	0°	$Ca_6Al_2S_3O_{18} \cdot 31H_2O$	H	?	X ∥ elong. G. = 1.48	261
1.4645		.0056	1.4649	1.4599	32°	$Na_2H_2P_2O_7 \cdot 6H_2O$	M	1–001	X∧cleav. = 15°	279
1.465		?	Weak		73°	Li_2SO_4	M	4–011, 101, 10$\bar{1}$	Ps.-octah. G. = 2.23	220
1.465		?	1.498	1.454	60°	K_2ZrF_6	M	1–001	Z∧cleav. = 45°	180
1.4658		.0066	1.4782	1.4622	57°	$Na_2HAsO_4 \cdot 7H_2O$	M	1–100	Z∧cleav. = 65°	271

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m D +	N_o or N_m D −	F−C Tl−Li	N_g	N_p or N_g-N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient, Color, etc.	Page
	1.4554 ↑	.0077	1.4608	1.4328	51°	$MgSO_4 \cdot 7H_2O(+NiSO_4 \cdot 7H_2O)$	O	1–010	X⊥010 cleav.	226
	1.4554 ↑	.0077	1.4608	1.4328	51°	$MgSO_4 \cdot 7H_2O(+ZnSO_4 \cdot 7H_2O)$	O	1–010	X⊥010 cleav.	226
1.4663		?	1.4791	1.4649	38°	$NH_4NaHAsO_4 \cdot 4H_2O$	M	None	Z∧elong. = 18°	271
1.4669		?	1.5657	1.4609	30°	$K_2S_2O_8$	T	1–010	Ext. Biref. G. = 2.48	263
1.4689		.0075	1.4779	1.4672	49°	$Rb_2Mg(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 21°	240
1.469		?	1.473	1.469	35°	SiO_2	O	Poor	Ps. Hex. 001 plates	191
1.469		?	1.480	1.463	Mod.	$Na_2CO_3 \cdot 2Na_2SO_4$	O	?	Penetr. twins	267
	1.4694	.0081	1.4724	1.4467	39°	$Na_2B_4O_7 \cdot 10H_2O$	M	3–100, 110	Z∧cleav. = 56°	213
	<1.47	?	Weak		0°	$(NH_4)_3ScF_6$	Q	?	G. = 1.80	177
1.470		?	1.508	1.457	61°	$MgCO_3 \cdot 5H_2O$	M	1–001	Efferves. HCl	203
1.4701		.0058	1.4731	1.4692	55°	$RbClO_4$	O	3–001, 110	Y⊥001 cleav.	206
	1.4720	.0088	1.4720	1.4395	0°	$BeSO_4 \cdot 4H_2O$	Q	None	Pyramidal	225
	1.472	?	1.487	1.455	80°	$Na_2B_4O_7 \cdot 4H_2O$	M	2–001, 100	Z ∥ cleav.	213
	1.472	?	Very weak		Sm.	$NaAlSi_2O_6 \cdot H_2O$	T	None	Trapezoh.	315
	1.4723	.0062	1.4723	1.4717	0°	$LiKSO_4$	H	Poor	X ∥ prism	215
1.473		?	1.485	1.465	75°±	$Na_2SiO_3 \cdot 6H_2O$	M	?	X∧*c* = 22°; Z = *b*	284
1.473		?	?	?	56°	$RbHSO_4$	O	?	X = *c*; Y = *b*	219
1.473		?	1.510	1.463	60°±	NH_4HSO_4	O	1–100	X = *a*; Z = *c*	219
1.4730		.0081	1.4786	1.4716	51°	$(NH_4)_2Mg(SO_4)_2 \cdot 6HO$	M	2–20$\bar{1}$, 010	X∧20$\bar{1}$ cleav. = 38°	240
1.4737		.0071	1.4769	1.4731	50°	$KClO_4$	O	3–001, 110	X⊥001 cleav.	206
	1.4738	.0064	1.4804	1.4653	82°	$HNa_3P_2O_6 \cdot 9H_2O$	M	?	Z ∥ 001 tablets	278
	1.475	?	Weak		0°	K_2TiF_6	R	?	G. = 3.01	180
	1.477	?	1.488	1.459	78°	$Li_2SO_4 \cdot H_2O$	M	2–101, 100	Z ∥ cleav.	221
1.477		?	1.484	1.471	84°	Na_2SO_4	O	1–001	Y⊥001 cleav.	216
1.4782		.09±	1.4856	1.4713	85°	$FeSO_4 \cdot 7H_2O$	M	3–001, 110	Z∧001 cleav. = 14°	231
1.4785		?	1.4867	1.4709	79°	$(Zn,Fe)SO_4 \cdot 7H_2O$	O?	?	?	227

1.4788	.0065	1.4804	1.4752	63°	$CsClO_4$	O	3–001, 110	$Y \perp 001$ cleav. G. = 3.33	206
1.479±	?	1.482	1.477	Lg.	$K_2Si_4O_9$	M?	?	Inclined ext.	283
1.479	?	1.487	1.472	Lg.	$(Fe,Cu)SO_4 \cdot 7H_2O$	M	1–001	$Z \wedge 001$ cleav. = 7°	232
1.48±	?	?	?	?	$CuSO_4 \cdot 7H_2O$	M	1–001	$Z \wedge 001$ cleav. = small	232
1.480±	?	1.486	1.473	Lg.	$NaPO_3$	M	?	Made at high temp.	277
1.4801 ↓	.0084	1.4836	1.4568	46°	$ZnSO_4 \cdot 7H_2O$	O	1–010	$X \perp 010$ cleav.	227
1.4807	.0075	1.4907	1.4767	67°	$Rb_2Mn(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 25°. Pink	243
1.482	.008	1.573	1.380	82°	$KHCO_3$	M	2–100, 001	$X \wedge 100$ cleav. = 30°	198
1.4821	.0078	1.4969	1.4759	67°	$K_2Fe(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 29. Green	244
1.4822	.0063	1.5036	1.4777	49°	$Na_4P_2O_6 \cdot 10H_2O$	M	2–010, 101	$Y \perp 010$ cleav. G. = 1.82	278
1.482–3	?	1.489	1.477	88°	$CoSO_4 \cdot 7H_2O$	M	3–001, 110	$Z \wedge 001$ cleav. = 14°. Pink	232
1.4833	.0068	1.4881	1.4818	70°	NH_4ClO_4	O	3–110, 001	$Y \perp 001$ cleav. G. = 1.95	207
1.4833	.0080	1.4969	1.4775	68°	$K_2Zn(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 31°	241
1.4840	.0082	1.4913	1.4801	70°	$(NH_4)_2Mn(SO_4)_2 \cdot 6H_2O$	M	2–$20\bar{1}$, 010	$X \wedge 20\bar{1}$ cleav. = 35°. Pink	243
1.4843	?	1.4870	1.4768	62°	$K_2H_2P_2O_6 \cdot 3H_2O$	O	?	$X \parallel$ elong.	278
1.4848	.0081	1.4948	1.4798	72°	$Rb_2Cd(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 26°	243
1.4852	.0060	1.4873	1.4557	29°	$NaH_2PO_4 \cdot H_2O$	O	?	$Z \parallel$ elong. G. = 2.06	270
1.4858	.0078	1.4916	1.4857	16°	$Cs_2Mg(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 5°	241
1.4864	.0084	1.5020	1.4836	47°	$K_2Cu(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 23°. Blue	245
1.4865	.0077	1.5004	1.4807	69°	$K_2Co(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 31°. Red	246
1.487	?	1.487	1.484	0°	SiO_2	Q	?	Twins. G. = 2.3	191
1.4874	.0078	1.4977	1.4815	73°	$Rb_2Fe(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 24°. Green	244
1.488	?	1.499	1.484	60°	$NaAl(SO_4)_2 \cdot 6H_2O$	M	1–100?	$Y \wedge$ elong. = 30°. G. = 2.3	261
1.488	?	1.489	1.485	84°	$Na_6Mg(SO_4)_4$	M	None	G. = 2.69	238
1.488	?	1.489	1.486	71°	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	M	None	$X \wedge c = 43°$. G. = 2.23	238
1.4884	.0078	1.4975	1.4833	74°	$Rb_2Zn(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 25°	242
1.4887	.0087	1.4959	1.4847	73°	$(NH_4)_2Cd(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 31°	243
1.4888	?	1.5719	1.4812	35°	$Rb_2S_2O_8$	M	None	001 tablets. G. = 3.13	263
1.4892	.0101	1.4911	1.4856	28°	$MgSeO_4 \cdot 6H_2O$	M	1–$10\bar{1}$	$Z \wedge 10\bar{1}$ cleav. = 20°	231
1.4893 ↓	.008±	1.4923	1.4693	42°	$NiSO_4 \cdot 7H_2O$	O	1–010	$X \perp 010$ cleav.	227
1.4897	.0066	1.5041	1.4855	57°	$Na_2H_2P_2O_6 \cdot 6H_2O$	M	1–001	$Z \wedge 001$ cleav. = 88°	278

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m			N_g or N_g-N_p	N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F − C Tl − Li								
	1.4899	?	1.5259	1.4793	60°	$HK_3(SO_4)_2$	M	1–001	Ps. Hex. twins. G. = 2.59	220
	1.49±	?	1.50	1.46	?	$(NH_4)_2MnF_5$	O	1–010	Y⊥010 cleav. G. = 2.37	177
	1.490	?	1.490	1.471	0°	$Na_2Mg(SO_4)_2\cdot\frac{5}{2}H_2O$	Q	1–001	X⊥ cleav. G. = 2.37	238
1.4906		.0084	1.5036	1.4886	45°	$Rb_2Cu(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 15°. Blue	245
1.491		?	1.497	1.490	50°	$MgSO_4\cdot 4H_2O$	M	2–100, 010	X∧100 cleav. = 81°	230
1.4915		.0082	1.4989	1.4870	77°	$(NH_4)_2Fe(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 34°. Green	244
1.4916		.0079	1.5051	1.4836	75°	$K_2Ni(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 33°. Green	247
1.4916		.0075	1.5014	1.4859	75°	$Rb_2Co(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 26°. Red	246
	1.492	?	1.493	1.482	45°	$MgSO_4\cdot 5H_2O$	T	None	Unstable. G. = 1.72	232
	1.492	?	1.547	1.435	Lg.	$Na_2CO_3\cdot 2\frac{1}{2}H_2O$	O	?	X ‖ elong. G. = 2.05	200
	1.493	?	?	?	?	$MgSO_4\cdot 2H_2O$	?	?	Fibrous masses	229
1.4930		.0086	1.4994	1.4888	79°	$(NH_4)_2Zn(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 35°	242
1.4947		.0067	1.4973	1.4935	67°	K_2SO_4	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
	1.495	?	1.495	1.49	0°	$(NH_4)_3UO_2F_5$	Q	?	Pyramidal. G. = 4.26	181
	1.495	?	1.495	1.460	0°	$CoSO_4\cdot 6H_2O$	Q	?	Also monoclinic	225
	1.495+	?	1.505	1.490	Lg.	NH_4PO_3	M	?	Platy. G. = 2.21	277
1.4953		.005±	1.5185	1.4820	75°	$Na_2S_2O_6\cdot 2H_2O$	O	2–110	X ‖ cleav. G. = 2.19	265
1.4953		.0087	1.5032	1.4902	82°	$(NH_4)_2Co(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ 20$\bar{1}$ cleav. = 36°. Red	247
1.4961		.0080	1.5052	1.4895	82°	$Rb_2Ni(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 29°. Green	247
1.4966		.0082	1.5025	1.4946	60°	$Cs_2Mn(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 17°. Red	244
1.497		?	1.555?	?	44°	$UO_2N_2O_6\cdot 6H_2O$	O	2–011	X ‖ 011 cleav. G. = 2.8	211
	1.498	?	1.504	1.465	50°	$CaN_2O_6\cdot nH_2O$	M	1	X⊥cleav.	211
	1.499	?	1.499	1.476	0°	$Sr(OH)_2\cdot 8H_2O$	Q	3–001, 110	Twins. G. = 1.88	187
1.4991		.0095	1.5139	1.4969	40°	$K_2Mg(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 30°	250
1.50±		?	Strong		Sm.	$K_2Si_2O_5\cdot H_2O$	?	?	Granular	284
1.50±		?	Strong		Sm.	$K_2SiO_3\cdot H_2O$	?	?	Granular	283

1.50±	?	Strong		Lg.	$2K_2SiO_3 \cdot H_2O$	O	1	Z ‖ elong. and cleav.	283
1.50±	?	?	?	?	$Ca_6Al_2S_3O_{18} \cdot 7H_2O$	H	?	Z ‖ elong.	261
1.50±	?	1.56	1.50	?	$CaSO_4$	M?	?	Lam. twin.	223
1.500	?	1.586	1.380	75°	$NaHCO_3$	M	3–$\bar{1}01$, 111	X∧a = 20°. G. = 2.22	198
1.5000	.0082	1.5062	1.4975	68°	$Cs_2Cd(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 15°	243
1.5007	.0089	1.5081	1.4949	87°	$(NH_4)_2Ni(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 37°. Green	247
1.5007	.0111	1.5027	1.4664	27°	$BeSeO_4 \cdot 4H_2O$	O	None	110 twins. G. = 2.03	226
1.5007	.0090	1.5054	1.4910	69°	$(NH_4)_2Cu(SO_4)_2 \cdot 6H_2O$	M	2–010, $20\bar{1}$	X∧$20\bar{1}$ cleav. = 23°. Blue	245
1.501	?	1.526	1.412	53°	$MgCO_3 \cdot 3H_2O$	O	2–110	Y ‖ cleav. G. = 1.85	203
1.5016	?	1.5866	1.4981	24°	$(NH_4)_2S_2O_8$	M	1 poor	Y ‖ elong. Z∧c = 27°	263
1.5017	?	1.502	1.471	9°	$Ba(OH)_2 \cdot 8H_2O$	M	1–001	X nearly ⊥ 001 cleav.	187
1.5021	?	1.5265	1.4794	89°	$NaH_2AsO_4 \cdot 2H_2O$	O	?	Ps. Octah. G. = 2.31	270
1.5021	.0127	1.5276	1.4959	52°	$H(NH_4)_3(SO_4)_2$	M	1–001	X∧001 cleav. = 18°	220
1.5031	.0095	1.5139	1.4969	47°	$Rb_2Mg(SeO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 30°	250
1.5035	.0082	1.5094	1.5003	75°	$Cs_2Fe(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 13°. Green	245
1.504	?	1.504	1.488	0°	$Ca_6Al_2S_3O_{18} \cdot 12H_2O$	H	?	X ⊥ 0001 plates. G. = 1.95	262
1.5048	.0080	1.5093	1.5022	74°	$Cs_2Zn(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 12°	242
1.505	?	1.508	1.497	50±	$Na_2Si_2O_5$	O	2–100, 010	X ⊥ 100 cleav.	282
1.5055	?	?	?	54°	$(NH_4)_2ZnCl_4$	O	?	010 lam. G. = 1.88	174
1.5056	.0141	1.5064	1.3346	7°	KNO_3	O	2–011	Y ‖ cleav. G. = 2.1	208
1.506	?	1.524	1.420	48°	$Na_2CO_3 \cdot H_2O$	O	1 poor	X = b. G. = 2.26.	200
1.5061	.0087	1.5153	1.5048	43°	$Cs_2Cu(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 1°. Blue	246
1.507	?	?	?	89°	$Ce_2(S_2O_6)_3 \cdot 15H_2O$	T	1–100	Bx. ⊥ 001±. G. = 2.29	266
1.507	?	Strong		72°	$HNa_3C_2O_6 \cdot 2H_2O$	M	1–100	Y∧100 cleav. = 6°	200
1.5079	.0079	1.5360	1.4886	81°	$Na_2S_2O_3 \cdot 5H_2O$	M	?	Z ⊥ 010 laths. G. = 1.7	266
1.508	?	1.514	1.495	Lg.	$MnSO_4 \cdot 5H_2O$	T	Poor	Y nearly ⊥ 100 plates	234
1.508	?	1.509	1.508	Sm.	$KAlSi_2O_6$	O?	None	Lam. twins.	309
1.5085	.0081	1.5132	1.5057	82°	$Cs_2Co(SO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 16°. Red	247
1.509±	?	1.513	1.503	Lg.	$K_2Si_2O_5$	O	2–001, 010	X ⊥ 001 cleav.	283
1.509 Li	.02±	?	?	64°	$K_2Cd(SO_4)_2 \cdot 1\frac{1}{2}H_2O$	M	1–010	Z ⊥ 010 cleav.	238
1.5093	.0106	1 5169	1.5070	58°	$(NH_4)_2Mg(SeO_4)_2 \cdot 6H_2O$	M	1–$20\bar{1}$	X∧$20\bar{1}$ cleav. = 32°	250

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m			N_g or N_g-N_p	N_p	2V	Substance	Syst.	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F−C Tl − Li								
1.4947	↑	.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
	1.5095	.0090	1.5095	1.4684	0°	KH_2PO_4	Q	None	X ‖ prism. G. = 2.34	268
1.5095		.011	1.5232	1.5095	0°	$Na_3VO_4\cdot 12H_2O$	R	?	Z ‖ prism	270
1.510		?	1.524	1.504	65°	$3Na_2O\cdot 2SiO_2\cdot 11H_2O$?	O	?	X = *a*; Y = *b*	284
1.510		.01±	1.516	1.504	84°	$LiAlSi_4O_{10}$	M	2–001, 201	X∧001 cleav. = 5°±	310
	1.510	?	1.521	1.488	69°	$Ca(UO_2)_2P_2O_8\cdot 12H_2O$	O	3–001, 100, 010	X⊥001 cleav.	275
	1.5109	.0095	1.5109	1.4873	0°	$NiSO_4\cdot 6H_2O$	Q	1–001	X⊥001 cleav. Green	225
1.512		?	?	?	62°	$K_2Mn(SO_4)_2\cdot 1\frac{1}{2}H_2O$	M	1–001	X∧⊥001 cleav. = 4°	238
	1.5129	.0083	1.5162	1.5087	87°	$Cs_2Ni(SO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 17°. Green	248
1.5133		.0070	1.5144	1.5131	30°	Rb_2SO_4	O	1–010	X⊥010 cleav. G. = 3.6	217
	1.514−	?	1.514	1.509	15°	$NaAlSiO_4$	T	?	Lam. twin. G. = 2.51	307
	1.514	?	1.518	1.504	50°	$Na_2Si_2O_5$	O	2–100, 010	X⊥100 cleav.	282
1.5140		.0100	1.5258	1.5094	66°	$Rb_2Mn(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 28°. Pink	252
	1.5167–74	?	1.5234	1.4084	27°	$KClO_3$	M	3–001, 110	Lam. twin. G. = 2.32	207
1.5168		?	Very weak		76°	$Th(SO_4)_2\cdot 8H_2O$	M	?	Z∧elong. = 65°	238
1.5179		.0098	1.5236	1.5178	19°	$Cs_2Mg(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 5°	250
	1.518	?	1.522	1.508	63°	$MnSO_4\cdot 4H_2O$	M	1–010	Y⊥010 cleav. Pink	231
1.5181		.0101	1.5335	1.5121	66°	$K_2Zn(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 32°	251
1.5182		.0104	1.5345	1.5095	64°	$K_2Fe(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 31°. Green	253
1.5183		.0105	1.5318	1.5153	53°	$Rb_2Cu(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 18°. Blue	254
1.52±		?	Very weak		0°	$KMg(Cl,Br)_3\cdot 6H_2O$	Q	None	Twinning	175
1.52		?	1.524	1.51	Sm.	$RbNO_3$	O	Poor	Z ‖ elong. G. = 3.12	209
	1.520	?	1.528	1.513	Lg.	Na_2SiO_3	O	2–110	Z ‖ cleav.	282
	1.520	?	1.520	1.512	0°	$CaMg_2Cl_6\cdot 12H_2O$	R	3–10$\bar{1}$1	G. = 1.67	168
1.5200		.0102	1.5328	1.5133	74°	$Rb_2Fe(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 28°. Green	253
1.5202		.0107	1.5288	1.5160	70°	$(NH_4)_2Mn(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 39°. Pink	252
1.521		?	.007		0°	$LiAlSi_2O_6$	Q	?	G = 2.41	307

1.521±	?	1.528	1.520	35°	K_2SiO_3	?	1	Z ‖ cleav.	283
1.5215	.01±	Very weak		0°	$K_3Cu(CN)_4$	R	?	Rhomboh.	164
1.5218	.0105	1.5380	1.5158	62°	$K_2Co(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 32°	255
1.522	?	1.522	1.519	0°±	$Mg_2Al_4Si_5O_{18}$	O	Poor	Ps. Hex. twins	317
1.5220	.0139	1.5220	1.5150	0°	$3Mg(NO_3)_2 \cdot 2La(NO_3)_3 \cdot 24H_2O$	R	?	Rhomboh.	211
1.5222	.0100	1.5331	1.5162	75°	$Rb_2Zn(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 28°	251
1.5225	.08±	1.5227	1.47±	7°	$CoSeO_4 \cdot 6H_2O$	M	1–10$\bar{1}$		231
1.5226	.0078	1.5296	1.5205	58°	$CaSO_4 \cdot 2H_2O$	M	1–010	$Y \perp 010$ cleav. G. = 2.32	229
1.5228	.0113	1.5349	1.5101	88°	$K_2Cu(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 27°. Blue	254
1.523	?	1.525	1.519	62°	$KAlSi_3O_8$	M	2–001, 010	$Z \perp 010$ cleav.	313
1.523	.0087	1.533	1.521	52°	$(NH_4)_2SO_4$	O	1–001	$X \perp 001$ cleav. G. = 1.77	216
1.5230	.0078	1.5438	1.5230	0°	$Cs_2S_2O_6$	R	?	Z ‖ elong.	263
1.5244	.0094	1.5373	1.5221	46°	$K_3Cr(CN)_6$	M	1–100	X nearly ⊥ 100 cleav. Yellow	177
1.5246	.0102	1.5246	1.4792	0°	$NH_4H_2PO_4$	Q	None	X ‖ elong. G. = 1.80	268
1.5249	.0142	1.5249	1.5176	0°	$3Mg(NO_3)_2 \cdot 2Ce(NO_3)_3 \cdot 24H_2O$	R	?	Rhomboh.	210
1.525	?	1.529	1.524	?	$Na_6Si_2O_7$	?	1	Plates. G. = 2.96	283
1.525	?	1.525	1.505	0°	$3NaAlSiO_4 \cdot (Ca,HNa)CO_3$	H	Poor	X ‖ elong.	326
1.525	?	1.544	1.515	73°	$NaCaB_5O_9 \cdot 5H_2O$	M	2–110	$Z \wedge 110$ cleav. = 12°	214
1.5255	.0141	1.5255	1.5182	0°	$3Mg(NO_3)_2 \cdot 2Pr(NO_3)_3 \cdot 24H_2O$	R	?	Rhomboh.	211
1.5256	.0107	1.5369	1.5199	74°	$Rb_2Co(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 29°. Red	255
1.526	?	1.685	1.474	65°	$NaHSO_3$	?	?		215
1.5260	.0111	1.5352	1.5206	77°	$(NH_4)_2Cd(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 36°	252
1.5266	.013	1.5705	1.5144	60°	$K_2UO_2(SO_4)_2 \cdot 2H_2O$	O	1–001	$X \perp 001$ cleav.	262
1.5266	.0140	1.5266	1.5192	0°	$3Mg(NO_3)_2 \cdot 2Nd(NO_3)_3 \cdot 24H_2O$	R	?	Rhomboh.	210
1.527	?	1.527	1.505	0°	$Ca_3Al_2O_6 \cdot 12H_2O$	H	?	X ‖ elong.	197
1.5272	.0107	1.5427	1.5181	73°	$K_2Ni(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 34°. Green	256
1.5279	.0102	1.5338	1.5250	69°	$Cs_2Mn(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 20°. Pink	252
1.528	?	1.528	1.524	0°±	$Mg_2Al_4Si_5O_{18}$	O	Poor	Ps. Hex. twins	317
1.528	?	1.543	1.469	55°	$2NH_4NO_3 \cdot (NH_4)_2SO_4$	O	2	X and Y ⊥ cleav.	267
1.5280	.0108	1.5381	1.5216	78°	$(NH_4)_2Fe(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 36°. Green	253
1.529	?	1.529	1.510	0°?	$Ca_4Al_2SO_{10} \cdot 6H_2O$	H?	?	Z ‖ elong.	262
1.5291	.0112	1.5291	1.5039	0°	$ZnSeO_4 \cdot 6H_2O$	Q	1–001	$X \perp 001$ cleav. G. = 2.33	226
1.5291	.0104	1.5390	1.5198	82°	$Rb_2Ni(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	$X \wedge 20\bar{1}$ cleav. = 31°. Green	256

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m D +	N_o or N_m D −	F−C Tl−Li	N_g or N_g-N_p	N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
	1.525	?	1.525	1.505	0°	$3NaAlSiO_4\cdot(Ca,NaH)CO_3$	H	Poor	X ∥ elong.	326
1.527		?	1.527	1.505	0°	$Ca_3Al_2O_6\cdot 12H_2O$	H	?	X ∥ elong.	197
	1.529	?	1.529	1.510	0°	$Ca_4Al_2SO_{10}\cdot 6H_2O$	H?	?	Z ∥ elong.	262
1.5295		.008	1.5436	1.5193	81°	$Na_4Fe(CN)_6\cdot 12H_2O$	M	Poor	X∧elong. = 16°	176
	1.5296	.0105	1.5296	1.5252	0°	$SrS_2O_6\cdot 4H_2O$	R	Poor	X⊥0001 plates	264
1.5298		.0108	1.5394	1.5282	48°	$Cs_2Cu(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 5°. Blue	254
1.530		?	1.537	1.524	?	Na_4SiO_4	?	?	Z∧twin. = 8°	282
	1.530	?	1.530	1.526	0°	$RbAlSiO_4$	H	?	Like nephelite	309
	1.53±	?	1.535	1.515	Lg.	$K_2Ca_2Si_9O_{21}$	M?	?		307
	1.530	?	1.530	1.48	0°	$K_2Ca(CO_3)_2$	H	1–0001	X⊥0001 cleav.	204
	1.530	?	?	1.512	?	$MgSO_4\cdot 5/4H_2O$	M?	?	Twins	229
1.530		?	1.535	1.495	44°	$KHSi_2O_5$	O?	2–100, 010	Z⊥100 cleav.	283
1.5300		.0113	1.5385	1.5240	82°	$(NH_4)_2Zn(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 38°	251
1.53+		?	1.545	1.525	Lg.	$Li_2Si_2O_5$	O?	3	Tabular. G. = 2.45	282
	1.531	?	Weak		0°	$LiAlSiO_4$	H	?	Granular. G. = 2.43	308
	1.531	?	1.541	1.426	35°	K_2CO_3	?	?	Ext. incl. to lam. twin.	199
	1.531	?	1.536	1.521	64°	$2NH_4NO_3\cdot(NH_4)_2SO_4$	O	1–001	X⊥001 cleav.	267
	1.5314	?	1.5363	1.4893	36°	$K_2H_2P_2O_6\cdot 2H_2O$	M	?	X∧001 plates=45°	278
	1.532	?	1.532	1.527	0°	$KAlSiO_4$	H	?	X ∥ elong.	308
1.532		.0082	1.539	1.528	74°	$NaAlSi_3O_8$	T	2–001, 010	Z∧010 cleav. = 75°	311
1.532 Li		?	Strong		87°	$BaS_2O_6\cdot 4H_2O$	M	2–110	X∧cleav. = 45°. G. = 3.1	266
1.5327		.0109	1.5417	1.5261	82°	$(NH_4)_2Co(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧20$\bar{1}$ cleav. = 40°. Red	255
	1.533	?	.007		?	SiO_2	?	?	Y ∥ fibers or at 29°	194
1.533		?	1.545	1.532	38°	$Na_6Be_6Si_4O_{17}$	O	?	G. = 2.55	306
	1.533	?	1.537	1.517	45°	$Ca_3O_4Cl_2\cdot 14H_2O$	O	1–001	X⊥cleav.	183

	1.533	?	1.540	1.514	Mod.	$(Zn,Cu)SO_4 \cdot 5H_2O$	T	Poor	Blue. G. = 2.1	233
	1.533	?	1.5330	1.5323	0°	$Ba(ClO_4)_2 \cdot 3H_2O$	H	?	Hygrosc. prisms	205
1.5331		.014±	1.5769	1.49±	Lg.	$Cd_2MgCl_6 \cdot 12H_2O$	O	2–100, 010	Y ⊥ 100 cleav.	169
	1.5344	.0115	1.5387	1.5201	55°	$(NH_4)_2Cu(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ 20$\bar{1}$ cleav. = 28°. Blue	254
	1.535	?	1.535	1.527	0°?	$Ca_4Al_2SO_{10} \cdot 6H_2O$	H?	?	Z ∥ elong.	262
	1.535	?	1.546	1.415	34°	Na_2CO_3	?	?	Lam. twin.	199
	1.535	?	?	1.533	Lg.	$FeSO_4 \cdot 4H_2O$	M	1–010	Z ⊥ 010 cleav. G. = 2.28	230
	1.535	?	1.545	1.460	38°	$CaCO_3 \cdot 6H_2O$	M	?	Z ∧ c = 17°. G. = 1.75.	203
1.535		?	Very strong		87°	$KMgBr_3 \cdot 6H_2O$	O	None	Ps. Tet. Y ∥ twin.	175
1.535		?	1.586	1.523	57°	$MgSO_4 \cdot H_2O$	M	4–11$\bar{1}$, 11$\bar{3}$	Z ∧ c = 76°. G. = 2.57	228
	1.535	?	?	?	50°±	$Mg_2Al_4Si_5O_{18}$	O	?	Fibrous	317
1.5352		.0103	1.5414	1.5306	83°	$Cs_2Fe(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 20°. Green	253
	1.536	?	1.5545	1.4227	42°	NH_4HCO_3	O	2–110	Z ∥ cleav.	198
	1.536±	?	Weak		?	Na_4SiO_4	?	?	Incl. ext. G. = 2.5	282
	1.536	?	1.542	1.526	Mod.	$FeSO_4 \cdot 5H_2O$	T	?	Green ±. G. = 2.2	233
1.5362		.0104	1.5412	1.5326	83°	$Cs_2Zn(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 20°	251
	1.5364	.07±	1.5364	1.4866	0°	$SrCl_2 \cdot 6H_2O$	R	1–0001	X ⊥ cleav. G. = 1.96	168
	1.537	?	1.537	1.533	0°	$NaAlSiO_4$	H	Poor	X ∥ elong. G. = 2.62	307
1.5370		.0110	1.5460	1.5285	86°	$(NH_4)_2Ni(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 40°. Green	256
1.538		?	1.538	1.520	0°	$Ca_3Al_2O_6 \cdot 8H_2O$	H	?	X ∥ elong. G. = 2.13	197
1.538		?	?	?	46°	$(NH_4)_3ZnCl_5$	O	?	Z ∥ elong. G. = 1.81	174
	1.538	?	1.538	1.406	0°	$NaLiCO_3$	H	?	X ∥ elong.	198
	1.538	.0101	1.543	1.512	56°	$CuSO_4 \cdot 5H_2O$	T	Poor	Blue±. G. = 2.28	233
	1.539	?	.007		?	SiO_2	?	None	Y ∥ fibers or at 29°	194
1.5390		.0098	1.5446	1.5352	77°	K_2SeO_4	O	2–010, 001	X ⊥ 010 cleav. G. = 3.1	218
	1.539	?	1.539	1.530	0°	$ZnCl_2 \cdot 6NH_3$	H	1–0001	X ⊥ cleav.	182
	1.5393	.0116	1.5393	1.5125	0°	$NiSeO_4 \cdot 6H_2O$	Q	1–001	X ⊥ cleav. G. = 2.31	225
1.5398		.013	1.5475	1.5398	0°	$Na_3VO_4 \cdot 10H_2O$	H	?	Z ⊥ 0001 plates	269
1.5399		.0110	1.5453	1.5354	87°	$Cs_2Co(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 22°. Red.	255
1.540±		?	1.675±	1.535±	32°±	CaS_4O_6	?	?		263
	1.54±	?	.008+		?	$K_2UO_2(NO_3)_4$	M	?	Green. G. = 3.36	210

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m D +	N_o or N_m D −	F−C Tl − Li	N_g or N_g-N_p	N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
	1.5296	.0105	1.5296	1.5252	0°	$(Sr,Pb)S_2O_6 \cdot 4H_2O$	R	Poor	X⊥001 plates	264
	1.525	?	1.525	1.505	0°	$3NaAlSiO_4 \cdot (Ca,NaH)CO_3$	H	Poor	X ‖ elong.	326
	1.535	?	?	?	50°±	$Mg_2Al_4Si_5O_{18}$	O	?	Fibers	317
	1.541	?	1.543	1.535	60°	$K_4CaSi_6O_{16}$	M?	?		307
1.5442		.0088	1.5533	1.5442	0°	SiO_2	H	None	G. = 2.65. Quartz	191
	1.545	?	1.545	1.533	0°	$K_2Al_2(SO_4)_4$	R	1–0001	X⊥cleav.	258
	1.5450	.0108	1.5489	1.5395	83°	$Cs_2Ni(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 24°. Green	256
1.546		.018	1.597	1.531	52°	$2Fe_2O_3 \cdot 5SO_3 \cdot 17H_2O$?	O	2–010, 001	X⊥001 cleav. Yellow	236
	1.547	?	1.547	1.504	0°	$Na_2Ca(CO_3)_2$	H	1–0001	X⊥cleav. G. = 2.54	204
	1.547	?	1.548	1.542	40°	$BaSiO_3 \cdot 6H_2O$	O	?	Z ‖ prism. G. = 2.59	300
1.5479		?	1.5592	1.5392	86°	$Di_2(SO_4)_3 \cdot 8H_2O(Nd)$	M	1–001	Z = *b*. Red to green	237
	1.548	?	1.550	1.530	Mod.	$CoSO_4 \cdot 5H_2O$	T	Poor	Pink. G. = 2.2	234
	1.548	?	1.548	1.537	0°	$K_8CaSi_{10}O_{25}$	H	?		306
1.549		?	1.5755	1.5433	51°	$Y_2(SO_4)_3 \cdot 8H_2O$	M	2–001, 10$\bar{1}$	X nearly⊥001	237
1.5494		.0066	1.5607	1.5399	85°	$Pr_2(SO_4)_3 \cdot 8H_2O$	M	2–001, 10$\bar{1}$	X⊥001±. Green	237
	1.5496	.0105	1.5496	1.54±	0°	$CaS_2O_6 \cdot 4H_2O$	R	Poor	X⊥0001 plates	264
1.55−		?	1.57	1.55	0°	$CaSO_4 \cdot \frac{1}{2}H_2O$	H	?	Z ‖ prism. G. = 2.55	226
	1.550	?	1.550	1.519	0°	$3NaAlSiO_4 \cdot CaCO_3$	H	?	X ‖ prism.	326
1.55		?	1.585	1.533	?	$H_2Al_2Si_4O_{12}$	M?	1–001	X⊥cleav.±. G. = 2.50	305
1.55		?	1.56	1.55	0°	$CsNO_3$	H	1–0001	Z⊥cleav. G. = 3.69	208
1.550		?	1.650	1.550	0°	μ-$CaCO_3$	H	?	Z⊥plates. G. = 2.54	202
1.550		?	1.558	1.547	55°±	$Li_2Si_2O_5$	O	3–001, 010, 100	Y⊥best cleav. G. = 2.45	282
1.55		?	Weak		?	$Al_2O_3 \cdot 3H_2O$	?	?		190
	1.55±	?	.018		0°	$Co\ ClO_4)_2 \cdot 6H_2O$	H	?	X ‖ elong. Pink	205
	1.55±	?	.016		0°	$Ni(ClO_4)_2 \cdot 6H_2O$	H	?	X ‖ elong. Green	205
	1.550	?	1.550	1.535	0°	$3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10H_2O$	H	0001?	Also monocl. twin.	183

1.5500	.017±	1.5680	1.5211	75°	$MgCrO_4 \cdot 7H_2O$	O	1–010	X⊥cleav. G. = 1.69	228
1.550	.019	1.635	1.533	Sm.	$Fe_2O_3 \cdot 4SO_3 \cdot 9H_2O$	O	3–001, 110	X⊥001 cleav. Red	236
1.5505	.0065	1.5621	1.5413	84°	$Nd_2(SO_4)_3 \cdot 8H_2O$	M	1–001	X nearly ⊥ cleav. Red	237
1.5513	?	1.5634	1.5498	39°	$K_3Rh(CN)_6$	M	?	Z ǁ elong.	178
1.5516	.010	1.5516	1.5414	0°	$CaS_2O_6 \cdot 4H_2O$	R	Poor	X⊥0001 plates	264
1.5519	.0065	1.5629	1.5427	82°	$Sm_2(SO_4)_3 \cdot 8H_2O$	M	1–001	X nearly ⊥ cleav.	237
1.552	?	1.563	1.552	0°	$ZrOCl_2 \cdot 8H_2O$	Q	2–100	Z ǁ cleav.	182
1.5533	.013	1.5695	1.5526	25°	$Na_2WO_4 \cdot 2H_2O$	O	1–001	Z⊥cleav. G. = 3.25	220
1.5535	.0079	1.5607	1.5382	68°	$NaH_2AsO_4 \cdot H_2O$	O	?	X ǁ elong. G. = 2.67	270
1.5537	.0100	1.5582	1.5515	68°	Rb_2SeO_4	O	2–010, 001	X⊥010 cleav. G. = 3.9	218
1.5547 Li	?	1.5710	1.5527	43°	$K_3Mn(CN)_6$	M	1–100	Z∧cleav. = 0°±. Red	177
1.556	?	?	?	?	$K_6Fe(CrO_4)_4 \cdot 6H_2O$	M	?	G. = 1.45	258
1.557	?	1.557	1.543	0°	$HfOCl_2 \cdot 8H_2O$	?	?	X ǁ prism	183
1.5580	?	1.5867	1.4874	63°	$Rb_2S_3O_6$	O	?	X ǁ elong.	263
1.560 ↓	?	?	?	50°±	$Mg_2Al_4Si_5O_{18}$	O	?	Fibers	317
1.560	?	1.560	1.503	0°	$AlCl_3 \cdot 6H_2O$	R	?	Deliques.	172
1.56±	?	?	?	56°	$(NH_4)_2SeO_4$	O	?	Y⊥010 plates	219
1.56±	?	1.565?	?	?	$CuSeO_4 \cdot 5H_2O$	T	?	Vert. striations. Red	234
1.56±	?	1.564	1.556	Sm.	$H_4Al_2Si_2O_9$	M?	1–001	X∧⊥001 = 2°. G. = 2.63	305
1.560	?	1.605	1.545	60°±	$CaS_2O_3 \cdot 6H_2O$	M?	?		266
1.5602	.0115	1.5788	1.5487	78°	$Li_2S_2O_6 \cdot 2H_2O$	O	1–100	Z⊥cleav. G. = 2.16	264
1.5608	.012±	1.91	1.5608	0°	$MgPt(CN)_4 \cdot 7H_2O$	Q	1–001	Z⊥cleav. Red; pleo.	168
1.5630	.0119	1.5846	1.5607	38°	$(NH_4)_2SeO_4$	M	3–100, 001, 010	Z∧100 cleav. = 67°	219
1.564	?	1.569	1.564	0°	$La_2(SO_4)_3 \cdot 9H_2O$	H	None	Z ǁ elong. G. = 2.82	235
1.5641	.0125	1.602	1.4934	70°	$K_2S_3O_6$	O	None	X ǁ prism. G. = 2.34	263
1.5644	.0087	1.5662	1.5598	65°	Cs_2SO_4	O	1–010	Y⊥cleav. G. = 4.24	217
1.565	?	1.565	1.515	0°	Na_2SO_3	H	?		215
1.565	?	1.566	1.561	Sm.	$H_4Al_2Si_2O_9$	M?	1–001	X∧⊥001 = 2°. G. = 2.63	305
1.565	?	1.57	1.56	?	$\beta\text{-}K_2Ca_3Si_6O_{16}$	O	?		307
1.565	?	1.608	1.556	48°	$K_2CdN_4O_8$	O	1–010	Z ǁ cleav. Yellow	212

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m			N_g or N_g-N_p	N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F−C Tl−Li								
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
1.5296		.0105	1.5296	1.5252	0°	$(Sr,Pb)S_2O_6 \cdot 4H_2O$	R	Poor	X⊥001 plates	264
	1.565	.08±	?	?	88°	$CdSO_4 \cdot 8/3H_2O$	M	1–010	X⊥cleav. G. = 3.05	230
	1.567	?	Weak		0°	$FeCl_2$	H	?	Green to brown	167
	1.567	?	1.572	1.428	15°	Li_2CO_3	M	2–001, $10\bar{1}$	Y∧001 cleav. = 15°±	199
	1.5674	.013	1.5674	1.5179	0°	KH_2AsO_4	Q	?	X ∥ prism. G. = 2.88	268
1.5689		.01±	1.5831	1.5660	49°	$K_3Fe(CN)_6$	M	1–100	Z∧cleav. = 4°. Red; pleo.	178
1.57±		?	1.61	1.535	Lg.	$NiCl_2 \cdot 6H_2O$	M	1–001	Z∧cleav. = 24°±	171
1.57±		?	1.639	1.508	?	$(NH_4)_2UO_2N_4O_{12} \cdot 2H_2O$	M	None	Ps. cubic. Yellow	211
1.570		?	1.579	1.564	75°	$Na_2Ca_3Si_6O_{16}$	O	?	Z ∥ elong.	306
	1.574	?	1.574	1.545	0°	$Ca(OH)_2$	R	1–0001	X⊥cleav. G. = 2.23	187
1.575		?	1.607	1.555	78°	$MnCl_2 \cdot 4H_2O$	M	?	Z ∥ elong. ±	170
	1.575	?	1.577	1.553	33°	$Ca(UO_2)_2P_2O_8 \cdot 8H_2O$	O	5–001, 100, 010	X⊥001 cleav. Yellow	275
	1.575	?	1.575	1.553	Sm.	$K_2(UO_2)_2P_2O_8 \cdot nH_2O$	M	?	Lam. twin. Yellow	276
	1.5754	?	1.588	1.5438	64°	$KPtCl_3 \cdot NH_3 \cdot H_2O$	O	None	X ∥ elong. Red	182
1.576		?	1.614	1.571	42°	$CaSO_4$	O	3–001, 010, 100	X⊥001 cleav. G. = 2.9	223
	1.5766	.0138	1.5766	1.5217	0°	$NH_4H_2AsO_4$	Q	None	X ∥ elong. G. = 2.32	269
1.577		?	1.635	1.562	56°	$Ba(ClO_3)_2 \cdot H_2O$	M	3–011, 100	Z∧100 cleav. ≐ 24°	207
1.577		?	1.618	1.554	75°	$CuSO_4 \cdot 3H_2O$	M	1–010	100 twins. Blue	230
	1.5772	?	?	?	78°	$K_4Fe(CN)_6 \cdot 3H_2O$	M	1–010	Z⊥cleav. G. = 1.9. Yellow	176
	1.58±	?	Weak		?	$Mg(UO_2)_2P_2O_8 \cdot 8H_2O$	?	?	001 plates	277
	1.580	?	Mod.		0°±	$NaH(UO_2)_2P_2O_8 \cdot 7.3H_2O$	?	?	001 plates	276
	1.580	?	1.580	1.574	0°	$Be_3Al_2Si_6O_{18}$	H	Poor	Green, etc. ±. G. = 2.7	317
1.58		?	Weak		?	$CsCeCl_4$	M	?	Ext. ang. = 11°	177
1.58±		?	.02		?	$H_2Al_2Si_4O_{12}$	O	1–001	X⊥cleav. G. = 2.50	305
1.58±		?	1.59	1.575	Lg.	$\alpha\text{-}K_2Ca_3Si_6O_{16}$	O	?		307

1.5818	.0107	1.5961	1.5700	85°	$Ca_2Fe(CN)_6\cdot 12H_2O$	T	1–100	X∧cleav. = 20°. Yellow	171
1.582	?	1.586	1.574	Mod.	$SrAl_2Si_2O_8$	T	None	Fibrous. G. = 3.04	319
1.583	?	Weak		?	$Al_2O_3\cdot 3H_2O$	?	?		190
1.5832	?	1.5885	1.5755	77°	$CaAl_2Si_2O_8$	T	2–001, 010	Z∧001 = 50°±	319
1.5837	?	?	?	54°	$K_4Ru(CN)_6\cdot 3H_2O$	M	1–010	Z⊥cleav. X∧c = 32°	176
1.584	.08±	?	?	18°	$MgPt(CN)_4\cdot C_3H_8O_3\cdot 5H_2O$	M	1–001	X∧elong. = 30° D	169
1.584	?	Mod.		?	$Na_2(UO_2)_2P_2O_8\cdot 6.5H_2O$	?	?		276
1.586	.024	1.640	1.572	Sm.	$Fe_2O_3\cdot 3SO_3\cdot 7H_2O$	M	?	Z⊥010 plates	237
1.5874	.0133	1.5874	1.3361	0°	$NaNO_3$	R	3–$10\bar{1}1$	N_c' on cleav. = 1.467	208
1.5884	.0109	1.5949	1.5705	75°	$Tl_2Mg(SO_4)_2\cdot 6H_2O$	M	1–$20\bar{1}$	X∧cleav. = 39°. G. = 3.57	241
1.5885	.04±	1.597	1.5885	0°	$MgSnCl_6\cdot 6H_2O$	R	3–$11\bar{2}0$	Z ∥ cleav. G. = 2.08	181
1.5906	.016±	1.5907	1.5906	0°	K_4CdCl_6	R	3–$10\bar{1}1$	Twins	173
1.591	?	1.611	1.591	0°	Li_2SiO_3	R	∥ elong.	Z ∥ elong. G. = 2.52	281
1.591 Li	?	?	?	58°	$K_2Cr_2O_7\cdot Hg(CN)_2\cdot 2H_2O$	O	2–110	Z⊥cleav.	265
1.592	?	1.592	1.582	0°±	$Cu(UO_2)_2P_2O_8\cdot 8\pm H_2O$	Q?	1–001	X⊥cleav.	275
1.593	?	1.600	1.587	70°±	$BaAl_2Si_2O_8$	M	1–001	X∧c = 3°. G. = 3.57	319
1.594	?	1.594	1.54	0°	$Na_2Mg(CO_3)_2$	H	3–$11\bar{2}0$	X ∥ cleav. G. = 2.73	204
1.5943	.0194	1.7163	1.5889	25°	$Na_2Ru(NO_2)_5\cdot 2H_2O$	M	None	X∧elong. = 6°. Orange	212
1.595	?	1.617	1.594	Sm.	$SrCl_2\cdot 2H_2O$	M?	?	G. = 2.67	170
1.595	?	1.632	1.562	90°	$MnSO_4\cdot H_2O$	M	1	Z⊥010. G. = 3.15	228
1.595	?	1.628	1.590	30°±	$CaSO_3\cdot 2H_2O$	?	?		215
1.5951	.0041	1.6072	1.5860	85°	$BaS_2O_6\cdot 2H_2O$	M	1–001		265
1.596	?	?	?	30°±	$Ca(UO_2)_2\cdot P_2O_8\cdot 8H_2O$	O	5–001, 100, 110	X⊥001 cleav. Yellow	275
1.597±	?	1.599	1.596	?	$Na_2Ca_2(SiO_3)_3$	?	?	Complex twin.	306
1.597	?	1.597	1.47	0°	$K_2Mg(CO_3)_2$	H	3–$11\bar{2}0$	X ∥ cleav. G. = 2.67	204
1.598	?	Weak		?	$Mn(UO_2)_2\cdot P_2O_8\cdot 7.6H_2O$	Q	1–001	"Ultra blue"	277
1.599	.010	1.637	1.599	0°	$SrSiO_3$	H	1–0001		286
1.5996	.0136	1.6084	1.5861	71°	$Tl_2Mn(SO_4)_2\cdot 6H_2O$	M	1–$20\bar{1}$	X∧cleav. = 33°. G. = 3.68	244
1.5999	.0115	1.6003	1.5989	72°	Cs_2SeO_4	O	2–010, 001	X⊥010 cleav. G. = 4.46	218
1.6±	?	2.055	1.5907	15°	$Y_2Pt_3(CN)_{12}\cdot 21H_2O$	O	1–001	Z⊥cleav. Red	178
1.6±	?	1.75	1.545	?	$NaAuCl_4\cdot 2H_2O$	O	?		178

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m										
D +	D −	F−C Tl−Li	N_g or N_g-N_p	N_p	2V	Substance	Syst.	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
	1.5296	.0105	1.5296	1.5252	0°	$(Sr,Pb)S_2O_6 \cdot 4H_2O$	R	Poor	X⊥001 plates	264
1.595		?	1.628	1.590	30°±	$CaSO_3 \cdot 2H_2O$	?	?		215
	1.596	?	?	?	30°±	$Ca(UO_2)_2P_2O_8 \cdot 8H_2O$	O	5–001, 100, 110	X⊥001 cleav. Yellow	275
	1.598	?	Weak		?	$Mn(UO_2)_2P_2O_8 \cdot 7.6H_2O$	Q	1–001	"Ultra blue"	277
1.599		.010	1.637	1.599	0°	$SrSiO_3$	H	1–0001		286
	1.600	?	1.600	1.590	0°	$Ca(UO_2)_2P_2O_8 \cdot 7H_2O$	O	5–001, 100, 110	X⊥001 cleav. Yellow	275
	1.60±	?	1.605	1.585	Sm.	$Ca_2P_2O_7$	?	?	Square to fibrous	279
1.60±		?	1.61±	1.59±	Sm.	Li_4SiO_4	O	?	Lam. twin. G. = 2.39	282
1.60		.019±	1.61	1.53	Sm.	$Na_2Pt(CN)_4 \cdot 3H_2O$	T	1–001	Ps. Hex. Always twin.	176
1.60		?	1.95+	1.60	0°	$CaN \cdot CN$	R	3–10$\bar{1}$1		155
1.600		?	1.605	1.600	0°	K_2CaSiO_4	H	?		306
	1.6007	.0119	1.6316	1.5883	66°	$Li_2K_2Fe(CN)_6 \cdot 3H_2O$	M	?	X∧elong. = 44°	176
	1.601	?	Weak			$Mn(UO_2)_2P_2O_8 \cdot 7H_2O$	Q?	?	"Ultra blue"	277
1.603		?	1.623	1.586	87°	Al_3BO_6	O	?	Z ∥ elong.	214
1.6038		?	?	?	0°	$(NH_4)_4CdCl_6$	R	?	Y ∥ elong. G. = 1.81	173
1.604		?	1.615	1.602	20°	$Mg_2P_2O_7$	M	3–110, 001	X∧110 cleav. = 15°	279
	1.6047	.010	1.6257	1.5670	72°	$Sr(ClO_3)_2$	O	?	X = *c*. Y = *a*.	206
1.605		?	1.630	1.597	Sm.	$CaSO_3 \cdot 2H_2O$	?	?		215
1.605		?	1.613	1.600	0°	$CaCl_2$	O?	2–110	Lam. twin. Deliques.	167
	1.605±	?	1.609	1.601	?	$KFeSi_3O_8$	M	?	Lam. twin. Yellow	314
1.6057		.0171	1.6435	1.5896	67°	$K_2S_4O_6$	M	1–100	Y = *b*; Z∧*c* = 33°	263
	1.6071	?	?	?	47°	$K_4Os(CN)_6 \cdot 3H_2O$	M	1–010	Z⊥cleav. X∧*c* = 30°	175
	1.608	?	1.608	?	0°±	$Cu(UO_2)_2P_2O_8 \cdot 6H_2O$	Q?	?	Green	277
1.609		?	1.625	1.609	0°	$Na_5Fe(SiO_3)_4$	H	?	Z ∥ elong.	310
	1.6093	.0161	1.6162	1.5929	69°	$Tl_2Fe(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 32°. G. = 3.65	245

1.6093	↓	.0157	1.6168	1.5931	69°	$Tl_2Zn(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 55°. G. = 3.72	242
1.6096		.0172	1.6190	1.5996	85°	$Tl_2Cu(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 31°. G. = 3.73	246
1.61±		?	1.612	1.605	70°?	$Ca_2SiO_4 \cdot H_2O$	O?	?	Z ∥ elong.	300
1.61±		?	1.90±	1.6088	Sm.	$NaKPt(CN)_4 \cdot 3H_2O$	M	?	Orange	176
1.61+		?	1.615?	1.604?	?	$LiAlO_2$	?	?	G. = 2.55	194
1.610		.011	1.654	1.610	Sm.	$CaSiO_3$	M	1–001	X∧cleav. = 3°	297
1.611		?	1.637	1.413	35°	NH_4NO_3	O	1–010	X⊥cleav. Z ∥ elong.	209
1.612		?	1.612	1.607	0°	$PtCl_2 \cdot 4NH_3 \cdot nH_2O$	Q	?	X⊥plates. Yellow	182
1.612	↕	?	1.621	1.597	75°	$BaSi_2O_5$	O?	3–010, 001, 100	Z⊥010 cleav.	287
1.613		?	1.613	1.604	0°+	$Ba(UO_2)_2P_2O_8 \cdot 6H_2O$	Q	?	Lam. twin.	277
1.617		?	1.652	1.617	0°	$Ca_3Al_{10}O_{18}$	Q	None	Also biaxial	196
1.6176		.0165	1.6238	1.6009	67°	$Tl_2Co(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 32°. Red	247
1.618±		?	?	?	Lg.	$ZnCl_2 \cdot 2NH_3$	O	3–011, 010	Y⊥010; X ∥ 011 cleav.	182
1.6183		.0130	1.6224	1.6024	62°	$Tl_2Ni(SO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 33°. Green	248
1.619		?	Weak		?	$KFeSi_2O_6$	?	?	Green. G. = 2.59	309
1.6198		.0174	1.6198	1.5922	0°	$(NH_4)_4Fe(CN)_6 \cdot 2NH_4Cl \cdot 3H_2O$	R	None	Yellow. G. = 1.49	174
1.62±		?	1.62±	1.615	40°±	$K_2Pt(CN)_4 \cdot 3H_2O$	O	None	Z ∥ prism. Colored	175
1.62±		.15±	1.696	1.6111	Mod.	$Rb_2Pt(CN)_4 \cdot 3H_2O$	M	?	Z = *c*±. Green	175
1.62±		?	1.63	1.61	?	$CaHPO_4$	T	?	Incl. ext. on 010	272
1.62±		?	1.625	1.608	?	$SrHPO_4$	O	?	Y⊥100 plates. G. = 3.5	272
1.62±		?	1.623	1.616	?	$ZnSiO_3$	O	?	Fibrous. G. = 3.52	288
1.62±		?	1.625	1.60	?	$(NH_4)_4UO_2(CO_3)_3$	M	1–001	Yellow. G. = 2.77	204
1.6205		.0195	1.6479	1.6205	0°	KIO_4	Q	?	Pyram. G. = 3.62	205
1.621		?	1.621	1.619	0°	$Sr_5F(PO_4)_3$	H	?	X ∥ prism	273
1.621		?	1.621	1.619	0°	$FeBaSi_4O_{10}$	Q	1–001	X = red. Z = pink. G. = 2.33	286
1.623		?	1.641	1.601	87°	$3CuO \cdot 2SO_3 \cdot 5H_2O$	T	2–100, 10$\bar{1}$	Z′∧*a* on 001 = 27°. Green	232
1.6233		?	1.9310	1.6204	13°	$LiRbPt(CN)_4 \cdot 3H_2O$	O	?	Z ∥ elong. Yellow	175
1.624		?	1.629	1.608	Lg.	$Zn_2(OH)PO_4$	O?	?	X = *a*. Y = *b*. Brown±	274
1.625		.010	1.645	1.620	54°	$Ba_2Si_3O_8$	O	1–001	X⊥cleav. G. = 3.93	288

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m D +	D −	F−C Tl−Li	N_g or N_y	N_p / $-N_p$	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
	1.5296	.0105	1.5296	1.5252	0°	$(Sr,Pb)S_2O_6\cdot 4H_2O$	R	Poor	X⊥001 plates	264
	1.608	?	1.608	?	0°±	$Cu(UO_2)_2P_2O_8\cdot 6H_2O$	Q?	?	Green	275
1.625		?	1.63	1.625	0°	$KAg(CN)_2$	R	None		164
	1.625	?	1.695	1.545	82°	NaCNS	O?	?	X ∥ elong.	183
	1.625–7	?	Very weak		?	$Pb(UO_2)_2P_2O_8\cdot 8H_2O$	Q?	1–001	X⊥001±	277
1.627		?	1.635	1.621	80°	$Ca_5Mg_2Si_6O_{19}$	O	?	Y ∥ elong.	287
1.627		.01±	Strong		84°	$H_8Na_6(MoO_4)_7\cdot 18H_2O$	M	Poor	Y∧elong. = 5°	266
1.6278		.012±	2.2916	1.6237	19°	$LiKPt(CN)_4\cdot 3H_2O$	O	None	Z ∥ elong. Red	175
	1.628	?	1.63±	1.628	0°±	$Cu(UO_2)_2P_2O_8\cdot 8H_2O$	Q?	3–001, 100	Green. Pleo. G. = 3.68	275
	1.629	?	1.631	1.616	39°	$CaSiO_3$	M	2–100, 001	Y ∥ cleav. G. = 2.92	297
	1.63±	?	1.658	1.570	65°	$K_2S_5O_6\cdot 3/2H_2O$	O	None	Z ∥ elong.	265
	1.63±	.022±	1.6331	1.5800	20°	$SrPt(CN)_4\cdot 5H_2O$	M	1–001	Z∧cleav. = 15°±	169
1.63±		?	1.635	1.617	?	$BaHPO_4$	O	?	Y = *a*. G. = 4.16	272
1.631		?	1.638	1.631	0°	$Ca_2MgSi_2O_7$	Q	1–001	Z⊥cleav. G. = 3.18	284
	1.6325	?	1.6325	1.629±	0°	$Ca_6F(PO_4)_3$	H	None	X ∥ elong. G. = 3.2	273
	1.633±	?	1.637±	1.57±	Sm.	$(NH_4)_2UO_2Cl_4\cdot 2H_2O$	T	?	Yellow. X<Y	181
	1.6330	.044±	1.6435	1.6217	87°	$Rb_2Mg(CrO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 1°. Yellow	257
	1.6337	.0155	1.6404	1.6250	78°	$Tl_2Mg(SeO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 43°. G. = 3.72	250
	1.635	?	1.635	1.626	0°	$3Ca_3P_2O_8\cdot CaCO_3$	H	?	X ∥ elong.	280
	1.635	.029	1.657	1.605	Lg.	$Fe_2O_3\cdot 3SO_3\cdot 6H_2O$	M	?	X∧elong. = 25°	236
1.6351–66		.0186	1.6531	1.6351	0°	$PbS_2O_6\cdot 4H_2O$	R	None	X⊥0001 plates. G. = 3.25	264
	1.6354	?	1.6354	1.6353	0°	$CaCuSi_4O_{10}$	Q	?	X = rose, Z = blue G. = 3.0	286
1.636		.007	1.647	1.634	63°	$BaSO_4$	O	3–001, 110	X⊥001 cleav. G. = 4.5	223
1.6371		.042±	1.6531	1.6363	27°	$(NH_4)_2Mg(CrO_4)_2\cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 39°. Yellow	257
	1.638	?	1.638	1.634	0°	$Ca_2OCl_2\cdot 2H_2O$	H	?	X ∥ prism	183

1.639	?	1.683	1.603	Lg.	$CoSO_4 \cdot H_2O$	M?	?	Incl. ext.	229
1.64−	?	1.670	1.620	Lg.	$BaS_5O_6 \cdot 7/2H_2O$	O	?	Y ⊥ tablets	265
1.64	?	1.67	1.64	0°	K_2PtCl_4	Q	?	Violet: X < Z. G. = 3.3	173
1.64	?	Strong		25°	$Ca_3P_2O_8 \cdot CaO$	M	Poor	Lam. twin. Z = c±	274
1.640	?	1.640	1.633	0°	$Ba_2Cl_2F_2$	Q	1–001	X ⊥ cleav. G. = 5.93	166
1.6411	.0166	1.6520	1.5962	51°	$Na_6P_2Mo_5O_{23} \cdot 14H_2O$	O	2–102	X ∥ cleav.	267
1.642	?	1.642	1.637	0°	$Ca_5ClP_3O_{12}$	H	None	X ∥ elong.	274
1.6425	.040±	1.6547	1.6369	67°	$Cs_2Mg(CrO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 38°. Yellow	258
1.6429	.0209	1.6531	1.6276	72°	$Tl_2Mn(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 40°. Pink	252
1.643	?	Strong		0°	$(NH_4)_3PdCl_3SO_3 \cdot H_2O$	R	3–11$\bar{2}$0	X = red, Z = yellow	267
1.643	?	1.673	1.643	0°	$KReO_4$	Q	?	Pyramidal	214
1.644	.025	1.767	1.622	48°	$CaPt(CN)_4 \cdot 5H_2O$	O	1–100	Z ⊥ cleav. Green	169
1.644	?	1.654	1.642	45°±	$Al_6Si_2O_{13}$	O	1–010	Y ⊥ cleav. Tinted±	304
1.644	?	1.644	1.638	0°	$3Sr_3P_2O_8 \cdot SrCO_3$	H	?	X ∥ elong.	280
1.645±	?	1.650	1.641	Lg.	$Ca_3Si_2O_7$	O?	?	Grains	287
1.645	?	1.654	1.642	60°	$\gamma\text{-}Ca_2SiO_4$	M	1–010	Z ∧ c = 3°	289
1.645	?	1.645	1.492	0°	$Hg(CN)_2$	Q	Poor	X ∥ elong. G. = 4.0	167
1.646	.01±	1.660	1.635	84°	$BaCl_2 \cdot 2H_2O$	M	None	Y ⊥ 010 plates. G. = 3.0	170
1.646±	?	1.653	1.639	87°	$CaMgSiO_4$	O	Poor	X ⊥ 010 cleav. G. = 3.2	293
1.647	.022	1.647	1.612	0°	$K_2CuCl_4 \cdot 2H_2O$	Q	?	X = blue, Z = green	174
1.6498	.0184	1.6560	1.6378	59°	$Tl_2Ni(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 38°. G. = 3.99	256
1.65±	?	1.65±	1.64±	?	$Cs_2MnCl_4 \cdot 2H_2O$	T?	1–001	Ext. at 45° on 001	176
1.65	?	Weak		?	$Al_2O_3 \cdot H_2O$	?	?	G. = 3.06	190
1.650	?	?	?	?	GeO_2	O?	?		194
1.650	?	1.655	1.650	0°	$Sr_5ClP_3O_{12}$	H	?	Z ∥ elong. G. = 4.87	273
1.651	.0107	1.669	1.636	85°	Mg_2SiO_4	O	Poor	Y ⊥ 001 cleav. G. = 3.22	289
1.651	.02±	?	?	56°	$CdCl_2 \cdot 2\frac{1}{2}H_2O$	M	1–001	Z ∧ ⊥ cleav. = 5°±	170
1.651	.026±	?	?	61°	$BaCdCl_4 \cdot 4H_2O$	T	2–110, 1$\bar{1}$0	X ⊥ 110±. G. = 2.97	171
1.651	?	1.651	1.627	0°	$Sr_2Cl_2F_2$	Q	1–001	X ⊥ cleav. G. = 4.62	166
1.6514	.0209	1.6589	1.6532	70°	$Tl_2Fe(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X ∧ cleav. = 39°. Green	253

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m			N_g	N_p	2V	Substance	Syst.	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F−C Tl−Li	or N_g-N_p							
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
1.631		?	1.638	1.631	0°	$Ca_2MgSi_2O_7$	Q	1–001	Z⊥cleav. G. = 3.18	284
1.644		?	1.654	1.642	45°±	$Al_6Si_2O_{13}$	O	1–010	Y⊥cleav. Tinted±	304
1.646±		?	1.653	1.639	87°	$CaMgSiO_4$	O	Poor	X⊥010 cleav. G. = 3.2	293
1.651		.0107	1.669	1.636	85°	Mg_2SiO_4	O	Poor	Y⊥001 cleav. G. = 3.22	289
1.653		?	1.658	1.650	31°	$MgSiO_3$	O	2–110	Z ‖ cleav. G. = 3.18	294
	1.6535	.0151	1.6590	1.6442	67°	$Tl_2Co(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 40°. Red. G. = 4.	255
1.6537		?	1.6748	1.6527	26°	$Mg_3B_2O_6$	O	2–110	Z ‖ cleav. G. = 2.99	214
	1.6539	.0215	1.6615	1.6414	69°	$Tl_2Zn(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 41°. G. = 3.96	251
1.654		?	1.660	1.651	54°	$MgSiO_3$	M	2–110	Z∧cleav. = 22°. G. = 3.19	294
1.654		?	1.668	1.654	0°	Be_2SiO_4	R	3–11$\bar{2}$0	Z ‖ cleav. G. = 3.0	286
	1.655	?	1.663	1.643	36°	$CaAl_2O_4$	M	2–110	X ‖ cleav. G. = 3.67	197
	1.656	?	1.682	1.540	51°	CaB_2O_4	O	1–100	X⊥cleav. G. = 2.65	214
	1.656	?	1.660	1.630	30°±	$Zn_3P_2O \cdot ZnO$	O?	?	Y ‖ *c*. Brown	274
	1.6565	.0198	1.6720	1.6396	85°	$Tl_2Cu(SeO_4)_2 \cdot 6H_2O$	M	1–20$\bar{1}$	X∧cleav. = 34°. Blue	254
1.6576		?	1.6666	1.6576	0°	$IrCl_3 \cdot 4NH_3 \cdot H_2O$	R	?	Z ‖ elong.	182
1.658		?	1.664	1.658	0°	$Sr_5ClP_3O_{12}$	H	?	Z ‖ elong. G. = 4.87	273
	1.6585	.0124	1.6585	1.4864	0°	$CaCO_3$	R	3–10$\bar{1}$1	Varied. G. = 2.71	201
1.66±		?	1.68	1.66	10°	$Ag_2CO_3 \cdot 4NH_3 \cdot H_2O$	O	3–010, 021	Y⊥010 cleav. 110 twins	200
1.66		?	1.68	1.65	?	$Ce_2Pt_3(CN)_{12} \cdot 18H_2O$	M	None	Yellow. G. = 2.66	178
	1.66±	?	1.67	1.65	?	$SrHAsO_4$	T	?	Ext. Ang. in 100 = 14°	273
	1.660	?	1.730	1.532	68°	KCNS	M	?	Z∧elong. = 16°	183
	1.662	.0175	1.665±	1.632±	33°	$Ag_2S_2O_6 \cdot 2H_2O$	O	2–110	Y ‖ cleav. G. = 3.62	265
1.665		?	?	?	?	$LiAlSi_2O_6$	M	?	G. = 3.17	307
1.665		?	1.670	1.649	Lg.	Ca_2ClPO_4	O	1–001	Z⊥cleav. G. = 3.17	274
	1.665	?	1.665	1.63	0°	Al_2O_3	H	1–0001	X⊥cleav. G. = 3.31	188

1.666	?	1.666	1.658	0°	$PtCl_2 \cdot 2NH_3 \cdot 4(PtCl_2 \cdot 4NH_3)$	Q	?	Yellow	182
1.6668	.010	1.6668	1.666±	0°	$Ca_5ClP_3O_{12}$	H	None	X ∥ elong.	274
1.6684	?	1.757	1.626	72°	$K_2PtBr_2N_2O_4 \cdot H_2O$	T	001?	Opt. Ax. ⊥ 001±. Yellow	212
1.669	?	1.669	1.665	0°	$Ba_5FP_3O_{12}$	H	?	X ∥ elong.	273
1.669	?	1.669	1.658	0°	$Ca_2Al_2SiO_7$	Q	1–001	X ⊥ cleav. G. = 3.04	317
1.669	?	1.670	1.658	Sm.	$ZnSO_4$	O	?	Z ⊥ 001 plates. G. = 3.7	224
1.67±	?	1.682	1.661	?	$Al_6Si_2O_{13}$	O	1–010	Y ⊥ cleav. G. = 3.03	304
1.670	?	1.670	1.645	0°	$(NH_4)_2CuCl_4 \cdot 2H_2O$	Q	?	Pyramidal. G. = 2.06	174
1.67±	?	1.67+	1.625	?	$CoCl_2 \cdot 2H_2O$	T?	2–010, 001	Incl. ext. on laths	171
1.670	?	1.670	1.658	0°	$Ca_2FeSi_2O_7$	Q	?	G. = 3.23	284
1.670	?	1.670	1.657	0°	$Ca_2(Fe,Zn,Mn)Si_2O_7$	Q	?		284
1.671	?	1.674	1.662	35°	$Ca_3Al_{10}O_{18}$	O	2–110	Z ∥ elong.	196
1.671	?	1.699	1.626	75°	$CuSO_4 \cdot H_2O$	?	?	Bluish-white	229
1.6715	.0105	1.694	1.664	59°	$CaMgSi_2O_6$	M	2–110	Z∧c = 39°. G. = 3.28	295
1.674	?	1.680	1.663	75°	$Ca(Mg,Fe)SiO_4$	O	Poor	G. = 3.2	294
1.674	.008	1.678	1.673	29°	$BaSiO_3$	O	1–010	X ∥ elong.	288
1.674±	?	1.680	1.665	Lg.	$2Ca_2SiO_4 \cdot CaCO_3$	O	2–001, 010		327
1.675	?	1.675	1.59	0°	$MgCl_2$	H	?	Deliques.	167
1.6769	?	1.6769	1.6294	0°	$4(NH_4)_2S_2O_3 \cdot AgBr \cdot NH_4Br$	Q	?		262
1.677	.019±	1.8982	1.6706	18°	$BaPt(CN)_4 \cdot 4H_2O$	M	?	Z∧elong. = 1°. G. = 3.05	170
1.678	?	1.699	1.648	78°	$K_2HgCl_4 \cdot H_2O$	O	?	Y ∥ elong.	174
1.678	.033	1.749	1.588	Lg.	$Fe_2O_3 \cdot 2SO_3 \cdot 5H_2O$	M	1–001	X∧cleav. = 52°. Twins	236
1.680	?	1.680	1.65	0°	Al_2O_3	H	1–0001	X ⊥ cleav. G. = 3.31	188
1.68±	?	1.685	1.675	Lg.	$Ca_3Al_2SiO_8$	O?	?	Z ∥ fibers. Pleo.	319
1.6802	?	Weak		88°	$Na_3AsS_4 \cdot 8H_2O$	M	?	Z∧elong. = 9°	159
1.681	.013	1.681	1.668	0°	$Ca_2BaSi_3O_9$	H?	3–11$\bar{2}$0	X ∥ fibers	286
1.681	.0138	1.6854	1.5300	19°	$CaCO_3$	O	3–010, 110	X ∥ cleav. G. = 2.88	201
1.684	?	1.742	1.644	81°	$CuCl_2 \cdot 2H_2O$	O	3–001, 110	X ⊥ 001 cleav. Green	168
1.685	?	1.94	1.685	0°	$AgCN$	?	?	Z ∥ prism	164
1.685	?	1.602	1.546	23°	NH_4CNS	M	?	Z∧elong. = 22°	184

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m			N_g or $N_g - N_p$	N_p	2V	Substance	Syst.	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F−C Tl−I								
1.4947		.0067	1.4973	1.4935	67°	$K_2SO_4(+K_2CrO_4)$	O	2–010, 001	Ps. Hex. twins. G. = 2.66	217
1.651		?	1.670	1.635	85°	Mg_2SiO_4	O	Poor	Y⊥cleav. G. = 3.22	289
	1.655	?	1.663	1.643	36°	$CaAl_2O_4(+CaFe_2O_4)$	M	2–110	X ∥ cleav. G. = 3.67	197
1.6715		.0105	1.694	1.664	59°	$CaMgSi_2O_6$	M	2–110	Z∧cleav. = 39°. G. = 3.28	295
1.687		?	1.713	1.687	0°	$ZnCl_2$	?	?		167
	1.69±	?	1.692	1.687	Lg.	$Ca_5Al_6O_{14}$	O?	?	X ∥ elong. Green±	196
	1.691	?	1.691	1.683	0°	$3Ba_3P_2O_8 \cdot BaCO_3$	H	?	X ∥ elong.	280
1.6994		?	1.751	1.6610	84°	$Na_2Cr_2O_7 \cdot 2H_2O$	M	None	Z∧c = 13°. G. = 2.53	266
1.7±		?	1.710	1.688	?	$Na_2ZrSi_2O_7$	M?	?	Very small ext. angle	281
	1.7±	?	?	1.7±	0°	$Na_{16}Cu_2Ag_4(S_2O_3)_8 \cdot 6NH_3$	Q	Poor	Blue: X<Z	262
	1.701	?	1.708±	1.69±	66°	$Ca(Fe,Mn,Mg)_2Si_3O_9$	T	2–110, $1\bar{1}0$	Opt. Ax.⊥cleav.±. Yellow	299
	1.701	?	1.701	1.699	0°	$Ba_5ClP_3O_{12}$	H	?	G. = 5.95	273
	1.702	.016±	?	?	70°	$BaCdBr_4 \cdot 4H_2O$	T	2–110, $1\bar{1}0$	X⊥110±. G. = 3.69	172
1.704		?	1.710	1.695	90°±	$Mn_2P_2O_7$	M	2–110	X∧cleav. = 4°. Yellow	279
	1.7054	.0187	1.7105	1.6749	Sm.	$Ca(Fe,Mn)SiO_4$	O	?	Yellow. G. = 3.34	294
	1.71±	?	1.72±	1.70±	?	$CaAl_2O_4 + 15\% CaFe_2O_4$	M?	2–110	X ∥ cleav. G. = 3.7±	197
	1.71±	?	1.72±	?	74°±	Rb_2CrO_4	O	1–001	X⊥cleav.	219
	1.710	?	1.755	1.639	74°	$3(NH_4)_2O \cdot TeO_2 \cdot 6MoO_2 \cdot 7H_2O$	T?	?	Six-sided plates	268
	1.715	?	Weak		0°?	Ca_3SiO_5	?	None	Granular and fibrous	286
	1.715	?	1.715	1.692	0°	$Na_4Zr_2Si_3O_{12}$	R	?	G. = 2.88	281
1.715		?	Very weak		Sm.	β'-Ca_2SiO_4	?	None		289
1.7174		?	1.812	1.7146	20°	$SrCr_2O_7 \cdot 3H_2O$	M	?	Z∧plates = 78°	266
1.719		?	1.733	1.719	0°	BeO	H	3–$10\bar{1}0$	Z ∥ cleav. G. = 3.	187
1.720		?	1.733	1.718	20°	Ca-Al-silicate	?	?	Brownish	318
1.720		?	1.737	1.715	Lg.	α-Ca_2SiO_4	M	?	X∧elong. = 18°	289
	1.725–6	.057	1.731	1.687	29°	K_2CrO_4	O	2–010, 001	Yellow. G. = 2.74	217
1.726±		?	1.735	1.717	Lg.	β-Ca_2SiO_4	O	2–010, 100	Z⊥010 cleav.	289

1.7266		.0213	1.7441	1.7129	84°	$BaBr_2\cdot 2H_2O$	M	Poor	Habit varied. G. = 3.69	170
1.7278		?	1.7361	1.7278	0°	$Na_3K(CrO_4)_2$	R	1–0001	Yellow. G. = 2.77	215
	1.730	?	1.730	1.726	0°	Ca-Al-silicate	?	?		317
1.732		.017	1.756	1.7275	33°	Sr_2SiO_4	M	?	X∧twin. = 17°	297
	1.733	?	1.739	1.724	Lg.	$CuSO_4$	O	?	Green, violet, etc.	224
	1.734	?	1.743	1.696	49°	$CaFeSiO_4$	O	?	Yellow. G. = 3.33	294
1.735±		?	1.739±	1.733±	?	$MnSiO_3$	T	3–110, 1$\bar{1}$0, 001	Pink. G. = 3.7±	299
	1.735	?	1.735	1.435	0°	$LiNO_3$	R	?	Hygrosc. G. = 2.33	208
1.736		?	1.742	1.730	90°±	$BaCl_2$	?	?		167
1.738		?	1.789	1.726	53°	$3CuO\cdot SO_3\cdot 2H_2O$	O	1–010	X⊥cleav. Green	228
1.738		?	1.8197	1.7202	52°	$K_2Cr_2O_7$	T	3–010, 100, 001	Red. G. = 2.69	264
	1.738	?	1.776	1.617	56°	$Mn_3B_4O_9$	T	2–001, 010	Opt. Ax.⊥001±. G. = 3.65	214
1.74		?	?	?	78°	$MgW_4O_{13}\cdot 8H_2O$	M	?	Y⊥001 plates±	266
	>1.74	?	Strong		Lg.	$Na_8Ti_5O_{14}$	M?	?	Angles of 117° and 130°	280
	>1.74+	?	Strong		Lg.	$K_2Ti_2O_5$	O	1–001	Y ∥ elong.	280
	>1.74+	?	Very strong		?	$SbBr_3$	O	1–010	Deliques.	172
	1.743	?	?	?	?	$Cu_2(OH)PO_4$	O	?		274
1.744		?	1.788	1.729	62°	$AgNO_3$	O	?	Z⊥001 plates. G. = 4.35	210
1.749		?	Strong		87°	$Sr_2SiW_{12}O_{40}\cdot 16H_2O$	M	?	Z∧elong. = 17°	267
High		?	Strong		Mod.	$Na_2Ti_2O_5$	O	1–001	X⊥cleav. Y ∥ elong.	280
>1.75		?	0.050		30°±	CaC_2	O?	3–001, 010, 100	Red, etc. Twins	155
1.757		?	1.819	1.757	0°	$4(NH_4)_2O\cdot Mn_2O_3\cdot 13MoO_3\cdot 9H_2O$	R	?	Yellow: X<Z	261
1.76±		?	0.03		60°	$CaFeSi_2O_6$	M	2–110	Z∧cleav. = 46°. Green	296
	1.76±	?	1.8+	1.720	?	Na_2ZrO_3	O?	?	Ps. Hex. twins. G. = 4	280
>1.76		?	Strong		0°	SeO_2	?	?	Z ∥ needles. G. = 3.96	194
	1.768	.0108	1.768	1.760	0°	Al_2O_3	R	None	Tinted±. G. = 4	188
1.770		?	1.840	1.710	Lg.	$CaV_2O_6\cdot 4H_2O$	T	1–010	Yellow. G. = 2.45	277
	1.770	.053	1.770	1.760	0°	$Fe_2(SO_4)_3$	R	3–10$\bar{1}$1	Yellow±	235
	1.771	?	1.800	1.728	77°	$4CuO\cdot SO_3\cdot 3H_2O$	O	1–010	Z ∥ elong. Green	228
	1.7761	?	1.7761	1.6788	0°	$Cs_3Ag_2Ba(CNS)_7$	O	1–001	X⊥cleav. G. = 3.03	184

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m			N_g or $N_g - N_p$		2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
D +	D −	F−C Tl−Li	N_g	N_p						
1.651		?	1.670	1.635	85°	Mg_2SiO_4	O	Poor	Y⊥cleav. G.=3.22	289
1.768		.0108	1.768	1.760	0°	Al_2O_3	R	None	Tinted±. G.=4	188
	1.777	?	Strong		Lg.	Cu_2SO_5	M	1–001	X⊥cleav.±. Brown	224
	1.78±	?	?	?	?	$FeAsO_4$	M	1–001	Yellow to brown	274
	1.78±	?	1.80±	1.76±	65°	Mn_2SiO_4	O	1–010	Gray to red±. G.=4	290
	1.781	.011±	1.781	1.773	0°	Al_2O_3+	R	None	Tinted±. G.=4	188
	1.784	.020	1.784	1.774	0°	$Cs_3Tl_2Cl_9$	H	?		177
	1.788±	?	1.790	1.741	Sm.	Na_2ZrSiO_5	O	?	Z ‖ elong. G.=3.6	281
	1.7909	?	1.7909	1.6527	0°	$K_2PtI_2N_2O_4\cdot 2H_2O$	Q	3–100, 001	X⊥001 cleav. Yellow	212
1.791		.024±	Very weak		?	$CsHgCl_3$	O	?		174
	1.795	?	?	?	?	$Ca_2Pb(SiO_3)_3$	?	?	G.=3.99	300
	1.8013	?	1.8013	1.6882	0°	$Cs_3Cu_2Ba(CNS)_7$	Q	1–001	X⊥cleav. G.=2.92	184
	1.8036	?	1.8036	1.7983	0°	Ag_2HPO_4	R	?	Prisms or 0001 plates	269
1.804		.054	1.918	1.783	Sm.	$Fe_2O_3\cdot 2SO_3\cdot H_2O$	O	?	Z ‖ elong. Yellow	235
	1.81±	?	2.08	1.80	9°	$PbCO_3$	O	4–110, 021	X ‖ elong. G.=6.57	202
	1.81±	?	.02–.03		Lg.	$KFeSi_2O_6$	M	2–110	X∧cleav.=2°. Green	309
	1.814	.058	1.818	1.802	60°	$Fe_2(SO_4)_3$	O	?	X⊥001 plates. Yellow±	235
	1.816	?	Strong		79°	$Ba_2SiW_{12}O_{40}\cdot 16H_2O$	M	?	Z∧elong.=14°	268
	1.816	.066	1.816	1.728	0°	$3Fe_2O_3\cdot 4SO_3\cdot 9H_2O$	R	None	Yellow: X<Z	235
	1.819	.035	1.836	1.776	60°	$NaFeSi_2O_6$	M	2–110	X∧c=8°. Yellow; green	314
	1.82	?	?	1.74	?	$H_4PbAs_2O_8$	T	?	Plates with 68°. G.=4.46	273
1.82±		?	1.83	1.81	?	Ba_2SiO_4	?	None	Granular	286
	1.82±	?	?	?	Lg.	$TlNO_3$	O	Poor	X ‖ elong.	210
	1.832	?	1.832	1.804	0°	$NaYSiO_4$	H	?	X ‖ prism	309
	1.843	?	1.880	1.730	Mod.	$KHg(CNS)_3$	?	?		184
1.8466		.014±	1.920	1.8466	0°	$AgBrO_3$	Q	Poor		205

1.859	.032	1.965	1.725	85°	$HgCl_2$	O	2–011	Y ∥ cleav.	167
1.8535	?	1.8535	1.6982	0°	$Cs_3Cu_2Sr(CNS)_7$	Q	1–001	X ∥ cleav. G. = 2.88	184
1.867	?	1.867	1.840	0°	$NaLaSiO_4$	H	?	X ∥ prism	309
1.867	?	1.867	1.840	0°	$KLaSiO_4$	H	?	X ∥ prism	309
1.8671	.0356	1.8853	1.8600	68°	Tl_2SO_4	O	2–010, 001	X ⊥ 001 cleav. G. = 6.76	217
1.870	?	1.870	1.843	0°	$LiLaSiO_4$	H	?	X ∥ prism	309
1.87	?	0.06		Sm.	$Fe_2O_3 \cdot H_2O(+H_2O)$	O	2–010, 100	Z ∥ elong. Yellow	189
1.877	?	1.886	1.835	47°	Fe_2SiO_4	O	1–010	X ⊥ cleav. Yellow	290
1.880	?	1.880	1.874	0°	$CaLa_2Si_2O_8$	H	?	X ∥ prism	317
1.889	?	1.889	1.861	0°	$NaPrSiO_4$	H	?	X ∥ prism	309
1.889	?	1.889	1.861	0°	$NaNdSiO_4$	H	?	X ∥ prism	309
1.898	?	1.898	1.867	0°	$NaSmSiO_4$	H	?	X ∥ prism	309
1.903	?	1.903	1.897	0°	$CaNd_2Si_2O_8$	H	?	X ∥ prism	317
1.9097	?	1.9765	1.8903	58°	$PbHAsO_4$	M	1–010	X ⊥ cleav. Y ∧ c = 38°	272
1.9200	.02±	1.9365	1.9200	0°	$CaWO_4$	Q	4–111	G. = 6.12	222
1.92	?	2.01	1.87	58°	As_2O_3	M	1–010	Z ∧ elong. = 6°. G. = 3.85	188
1.921	.02±	1.923	1.919	0°	$SrMoO_4(+2\%Ce_2Mo_3O_{12})$	Q	?	Yellow. G. = 4.15	222
1.9266	.02±	1.9412	1.9266	0°	$CaWO_4(+10\%Ce_2W_3O_{12})$	Q	4–111	Yellow	222
1.949	.02±	1.953	1.949	0°	$SrMoO_4(+40\%Ce_2Mo_3O_{12})$	Q	?	Yellow	222
1.9592	.0492	1.9640	1.9493	73°	Tl_2SeO_4	O	2–010, 001	X ⊥ 010 cleav. G. = 6.87	218
1.96±	?	Weak		58°	S	M	?	X ∧ c = 44°. G. = 1.05	153
1.9690	.0412	1.9690	1.9322	0°	$Pb_3(PO_4)_2(+CePO_4)$	H	?	X ∥ elong.	272
1.9702	.0406	1.9702	1.9364	0°	$Pb_3(PO_4)_2$	H	?	X ∥ elong.	272
1.96	?	.01±		?	$6Na_2O \cdot Fe_2O_3 \cdot 5SiO_2$	?	?	Complex twins	310
1.9733	.0353	2.6559	1.9733	0°	Hg_2Cl_2	Q	2–100	Z ∥ cleav. G. = 6.48	166
1.974	.023±	1.984	1.974	0°	$CaMoO_4$	Q	4–111	G. = 4.35	222
1.993	.024±	2.002	1.993	0°	$CaMoO_4(+Y_2Mo_3O_{12})$	Q	4–111		222
1.9968	.0247	2.0929	1.9968	0°	SnO_2	Q	2–100	Tinted±. G. = 7.0±	191
2.0004	.026	2.0049	2.0004	0°	$CaMoO_4$, etc.	Q	4–111		222
2.004	.081	2.020	2.004	0°	ZnO	H	1–0001	Red. G. = 5.6±	187
2.006	?	2.006	2.001	0°	$CaMoO_4(+Di_2Mo_3O_{12})$	Q	4–111	Violet	222

TABLE II.—ANISOTROPIC ARTIFICIAL INORGANIC SUBSTANCES—*continued*

N_o or N_m D +	N_o or N_m D −	F−C Tl−Li	N_g or N_g-N_p	N_p	2V	Substance	System	Cleavage	Crystal Habit, Optic Orient., Color, etc.	Page
	1.87 ↑	?	0.06		Sm.	$Fe_2O_3 \cdot H_2O(+H_2O)$	O	2–010, 100	Z ∥ elong. Yellow	189
	2.006	?	?	2.006	0°	$Pr_2(MoO_4)_3$	Q	?	Green. G. = 4.84	234
	2.023	.026	2.023	2.021	0°	$Nd_2(MoO_4)_3$	Q	?	Violet. G. = 5.14	234
	2.026	.033±	Weak		0°	$Di_2(MoO_4)_3$	Q	?	X⊥001 plates. G. = 4.96	234
2.03±		.03±	Very weak		0°	$Y_2(MoO_4)_3$	Q	1–001		234
2.03		?	?	?	?	$Pb_2As_2O_7$	?	?	G. = 6.85	279
2.0377		.078	2.2454	1.957	69°	S	O	Poor	Yellow. G. = 2.07	153
	2.04	.08±	2.07	1.97	Mod.	$4CaO \cdot Al_2O_3 \cdot Fe_2O_3$	?	?	Brown: X<Z. G. = 3.77	196
	2.04	.033	2.04	2.028	0°	$Ce_2(MoO_4)_3$	Q	?	Yellow. G. = 5.03	235
2.046		?	?	1.908	Lg.	N_4S_4	O	?	Ps. Isom. Twins. Red	159
	2.09	?	2.09	1.94	0°	$Pb_3(OH)_2(CO_3)_2$	H	1–0001	X⊥cleav. G. = 6.14	203
	2.142	?	2.142	2.030	0°	$H_2K_2TeI_2O_{10} \cdot 2HO$	R	None	Twins	207
	2.16	?	2.16	2.13	0°	$Pb_5Cl(AsO_4)_3$	H	?	X ∥ elong. G. = 7.15	274
2.2172		.05±	2.260	2.199	67°	$PbCl_2$	O	1–001	Z⊥cleav. G. = 5.84	168
2.218		.143	2.229	2.218	0°	AgI	H	1–0001	Yellow. G. = 5.6	164
2.22 Li		.10±	2.29	2.20	Mod.	$Ca_2Fe_2O_5$	M?	None	Brown: X>Y=Z	196
	2.229	?	?	?	0°	PbO_2	Q	2–110	Brown. G. = 8.56	191
	2.25 Li ↑	?	2.25	2.13	0°	$CaFe_2O_4(+10\%CaAl_2O_4)$	?	?	Acicular. Red	196

2.356	↓ ↓	.05±	2.378	2.356	0°	ZnS	H	3–11$\bar{2}$0	Yellow. G. = 4.09	157
2.394	↓	?	2.400	2.260	Sm.	$Fe_2O_3 \cdot H_2O$	O	2–010, 100	Extr. disp. Yellow	189
2.42		?	2.44	2.42	0°	CdS	H	3–11$\bar{2}$0	Yellow	158
2.46		?	2.48	2.46	0°	ZnS(+FeS)	H	3–11$\bar{2}$0	Brown	157
2.5±	↑	?	2.5	2.3	0°	$Fe_2O_3(+H_2O)$	H	?	X || fibers. Red. G. = 4.7±	189
2.5±		?	?	?	0°	Cr_2O_3	R	3–10$\bar{1}$1	Green. G. = 5.2	189
2.506		.15±	2.529	2.506	0°	CdS	H	3–11$\bar{2}$0	Yellow. G. = 4.82	158
2.58	↓	.24±	2.58	2.43	0°	$CaFe_2O_4$	?	?	Acicular. Red	196
2.58 Li		?	2.82	2.58	0°	HgS	H	?	Red. G. = 7.2	158
2.58 Li		?	2.60	2.48	26°	$AgAsS_2$	M	?		159
2.59 C		?	2.59	2.23	0°	AsI_3	H	1–0001	X⊥cleav. Red	172
2.6 Li		?	Extreme		0°	$AgAsS_2$	R	?	Red: X<Z	159
2.61 Li		?	2.71	2.51	Lg.	PbO	O	1–100	Yellow: X<Z. G. = 9.29	186
2.654		.072	2.697	2.654	0°	SiC	H	Poor	Tinted±. G. = 3.2	155
2.665 Li		?	2.635	2.535	0°	PbO	Q	2–100	X || cleav. Yellow-red	186
27 (700)		?	2.75	2.7	0°	Al_4C_3	H	1–0001	Z⊥cleav.	155
2.7	↓	?	2.7	2.6	0°	$Fe_2O_3(+H_2O)$	H	?	X || fibers. Red. G. = 4.7±	189
2.7		.26±	2.75±	2.42	Sm.	$Pb_3Cr_2O_9$	O?	1	X || elong. Scarlet	224
2.748		?	2.748	2.455	0°	HgI_2	Q	1–001	Red: X<Z	166
2.78 Li		?	2.78	2.36	0°	SbI_3	H	?	X⊥plates. Red	172
2.81 Li		?	3.14	2.81	0°	HgS	H	3–11$\bar{2}$0	Z || cleav. Red. G. = 8.17	158
2.84		.5±	Strong		?	CuO	M	2–111, 001	X⊥plates±. G. = 6.45	187
>2.95		?	>2.95	2.74	0°	Fe_2O_3	H	?	X⊥0001 plates. Red	189
3.00		?	4 04	3.00	0°	Se	H	?	Metallic. G. = 4.79	153

INDEX

The determinative tables are not included in the index since any substance is easily found in them by means of its index of refraction (N, N_o or N_m).

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